NASA CR-135431
PWA-5512-17

(NASA-CR-135431) SHORT-TERM PERFORMANCE DETERIORATION IN JT9D-7A(SP) ENGINE 695743 (Pratt and Whitney Aircraft Group) 236 p HC A11/MF 01 CSCI 21E

N78-30121

Unclas
G3/07 28556

NASA

SHORT-TERM PERFORMANCE DETERIORATION IN JT9D-7A(SP) ENGINE 695743

JT9D JET ENGINE DIAGNOSTICS PROGRAM

R. J. Bouchard, W. R. Beverly, and G. P. Sallee

UNITED TECHNOLOGIES CORPORATION
Pratt & Whitney Aircraft Group
Commercial Products Division

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Lewis Research Center
Contract NAS3-20632



PREFACE

The requirements of NASA Policy Directive NPD 2220.4 (September 14, 1970) regarding the use of SI Units have been waived in accordance with the provisions of paragraph 5d of that Directive by the Director of Lewis Research Center.

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SECTION 1.0

SUMMARY

This report presents the results of special testing and an analytical teardown of a short-term JT9D-7A service engine undertaken under NASA Contract NAS3-20632. These activities were part of studies directed at determining the cuases for short-term performance deterioration.

The objective of this test and analytical teardown program was to monitor the performance losses as they occurred from prior to first flight through introduction into airline service on new production engines. An engine was selected from those being monitored and was returned to Pratt & Whitney Aircraft for extensive testing and a complete analytical teardown to determine the level and module contribution to the performance loss and the specific causitive factors.

In selecting an engine to be subjected to this special program, the performance of two engines was monitored from prior to initial delivery through the early introductory service of Pan American World Airways Special Performance 747 aircraft number N536PA. These data provided the basis for selection of the inboard engine, serial number P-695743, and its introduction into the test program. The engine was received and tested "as is" in the original production test stand; this testing showed an increase of 1.5 percent in thrust specific fuel consumption (TSFC). The engine was retested after engine vane control (EVC) trim and water and detergent washing to remove surface contamination, reducing the level of TSFC deterioration by 0.3 percent. The engine was then disassembled to permit the installation of fully instrumented engine cases and was retested in an experimental test stand to permit the evaluation of modular performance.

A complete analytical teardown of the engine was conducted, and the condition of all seals and parts affecting performance was documented, from which the performance of each module was estimated. These results were then compared with analysis of the engine test data to achieve a final assessment of the causes for short-term deterioration at the module level. The performance testing of the engine showed that the overall short-term deterioration was distributed by module as shown in the tabulation below:

Module	ΔTSFC Since New (%)
Fan	+0.15
Low-Pressure Compressor	+0.35
High-Pressure Compressor	+0.12
High-Pressure Turbine	+0.47
Low-Pressure Turbine	+0.10
Total	+1.19

This level of deterioration correlated well with specific hardware deterioration in the engine and with other historical short-term deterioration data.

The cause of short term deterioration is distributed between all of the modules or components of the engine, and the summation of these individual losses make up the total short-term engine performance deterioration. The major fundamental cause of this deterioration is increased operating clearances in the engine associated with the aircraft operating environment and, to a lesser extent, second-stage turbine vane distortion and increased roughness of fan and low-pressure compressor airfoils.

SECTION 2.0

INTRODUCTION

The rapid rise in the cost of oil since the OPEC oil embargo in 1973 has resulted in a national effort to increase the availability of domestic oil, develop alternate sources of energy, and to develop both near and far term means to reduce fuel consumption. This national requirement for reduced fuel consumption, as applied to commercial airplane operation, is the thrust of the NASA Aircraft Energy Efficiency (ACEE) Program. The NASA activity on reducing fuel consumption in commercial aircraft propulsion systems is the objective of the NASA Energy Conservative Engine Office (ECEO) which is addressing both near term and long term solutions. The long term program is directed at demonstrating the technology to reduce engine fuel consumption by 12 to 15 percent through demonstration of very advanced engine technology for application in the late 1980 time frame. In the nearer term, the Engine Component Improvement (ECI) Program is directed at improving the fuel consumption of current engines with a goal of a 5 percent reduction over the life of the engine starting in the 1980 to 1982 time period. Two approaches are being undertaken to achieve this near term objective. The first approach is to improve the performance of existing engines by demonstrating improved component performance levels (NASA Performance Improvement Program). The second approach is to examine the losses in engine performance that occur during service use to determine the causes of performance deterioration and to identify corrective actions to permit the retention of new engine performance levels over long periods. These efforts of engine are being undertaken under the NASA Engine Diagnostics Program.

Engine performance deterioration can be generally divided into two time frames: (1) the performance loss that occurs over the first few flights, called short term or instant performance deterioration, which is characterized by a rapid rate of loss in TSFC performance; and (2) long term performance deterioration which occurs more gradually. This report covers test and analytical work to determine the cause of short term performance deterioration in the JT9D engine.

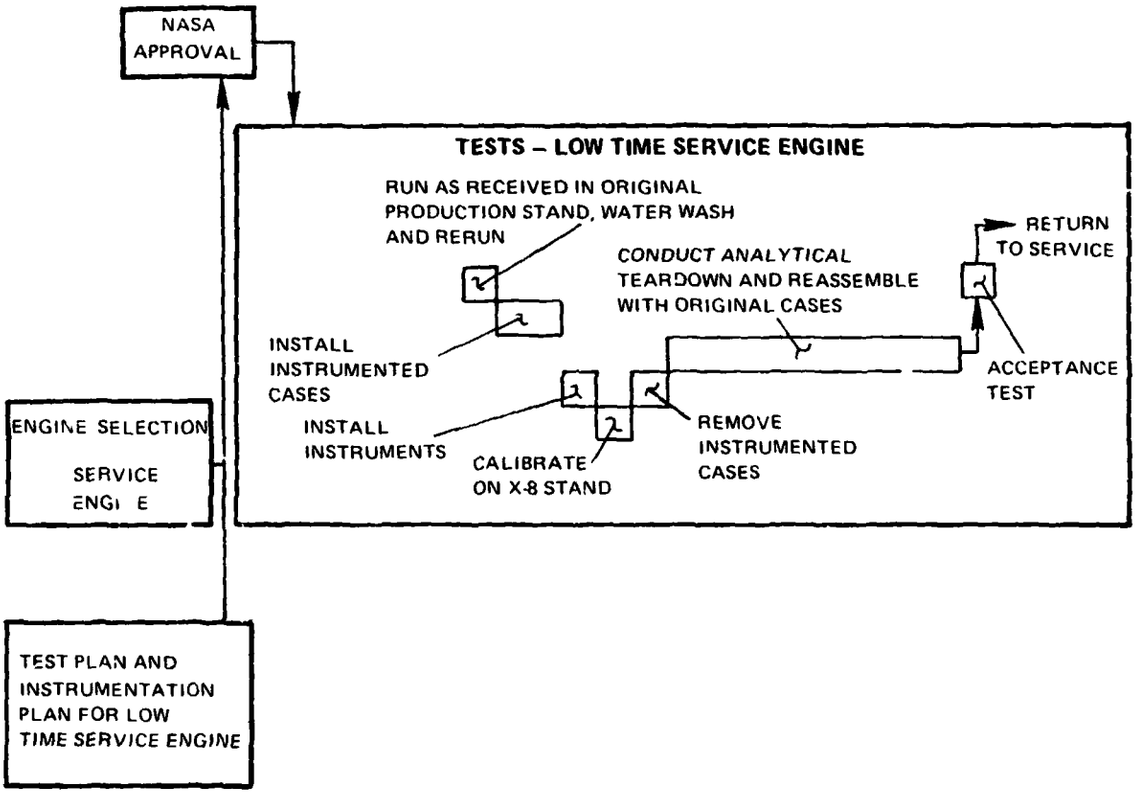
Historical performance data obtained from engines that had been subjected to the flight environment for from only a few to 250 flights indicate that the JT9D-3A/7/20 series of engines average approximately 1 percent loss in thrust specific fuel consumption on the first flight relative to their individual new production performance. Further, this loss in thrust specific fuel consumption grows from 1 percent to 1.5 percent by the 200th flight. The bulk of the data concerning short term performance deterioration is from engines returned to Pratt & Whitney Aircraft, after airframe manufacturer flight testing, which were tested as received and prior to any refurbishment or repair. The performance testing was accomplished with standard production type instrumentation, and the limited nature of these data creates difficulties in properly distributing the performance losses to the individual modules of the engine. Additionally, these engines were only partially disassembled, and detailed data which would permit an understanding of the causitive factors or damage mechanisms causing the performance losses were not obtained.

The overall objective of the low-time service engine test, reported herein, was to: (1) document the overall and module/component performance deterioration experienced by an engine in the first few hundred flights after entry into commercial services, and (2) to permit

identification of the damage mechanisms responsible for the loss in performance. The technical plan for accomplishing this objective is shown in the chart below. The test program included three basic elements: "as-received" calibrations in a production test stand, calibration with expanded instrumentation in an experimental test stand, and detailed analytical teardown inspection of the engine.

The objective of the "as-received" calibration in the production test stand was to establish the level of overall engine performance deterioration as measured in the same test stand and in the same configuration as used for the original production acceptance test. The water wash and recalibration in the production test stand was undertaken to separate the effects of gas path contamination from deterioration caused by mechanical damages. Production testing, even with additional instrumentation permitted by production cases, provides significantly less data than is required for accurate assessment of module performance. The objective of the expanded instrumentation calibration was to overcome these difficulties and permit documentation of the individual module/component performance levels from which an assessment of module deterioration could be made. The objective of the post-test analytical teardown inspection was to document the seal rub patterns, clearances, and conditions of parts throughout the engine to provide a basis for correlating the assessed module/component performance deterioration with the condition of engine hardware.

Section 3.0 describes the process for selection of the low-time test engine. Section 4.0 presents the test results which establish the over-



all level of engine performance deterioration and Section 5.0 presents module/component performance loss assessments as well as analytical teardown results. Conclusions and recommendations resulting from the test program are presented in Sections 6.0 and 7.0, respectively.

Several appendices are included in this document to provide more detailed information than is amenable to the main body of the text. These appendices include the following.

A. Facilities and Procedures
B. Teardown Procedures
C. Quality Assurance Report
D. Fuel Analysis
E. Production Stand Log Sheets
F. Experimental Stand Log Sheet Summaries
G. Analytical Teardown Photographs
H. Post-Teardown Calibration Log Sheet Summary
I. Program Chronology
J. Nomenclature

SECTION 3.0

ENGINE SELECTION

3.1 SELECTION PROCESS

In order to accomplish the program objectives, a low time service engine was required, and a source of a low time engine had to be identified early to permit monitoring of the performance changes that occurred on the first flight and initial service use. Through the cooperative efforts of Pan American and the Boeing Commercial Aircraft Company, plans were developed to install expanded instrumentation on two of the four engines on Pan Am's new 747SP Serial Number N536PA to be delivered in early May of 1977.This aircraft has had two of its engines, P-695745 in the No. 1 position (outboard) and P-695743 in the No. 2 position (inboard), instrumented since new for on-the-wing data acquisition with the Plug-In Console (PIC) system. Several on-the-wing performance calibrations were run on these engines prior to the removal of P-695743. Table I defines the timing of these PIC tests, and Figure 1 is a sample of the data from a typical PIC test. In addition, provisions had been made with Pan American to obtain expanded in-flight engine calibrations after each PIC test. Table II defines the timing of the flight data acquisitions, and Figure 2 is a sample of the data obtained. These data were used in monitoring deterioration and in program decision-making with respect to which engine to remove and when.

By the time that a satisfactory spare engine could be obtained, both engines P-695743 and P-695745 had accumulated 1081 in-flight hours and 141 take-off cycles. This operating time was higher than the originally planned 300 to 500 in-flight hours; however, with the long flights of this aircraft, a relatively low number of flight cycles (141) had been accumulated. This number of flight cycles is commensurate with that typically accumulated on domestic aircraft with 300 to 500 hours of operating time.

TABLE I
PLUG-IN CONSOLE TESTS OF JT9D-7A(SP) NO. 1 AND NO. 2 ENGINES ON N536PA AIRCRAFT

Date	Hours	Cycles	Location
April 21, 1977	0	0	Boeing; Seattle, Wash.
May 9, 1977	18	11	J.F. Kennedy; New York
May 16, 1977	110	19	J.F. Kennedy; New York
May 19, 1977	155	23	J.F. Kennedy; New York
June 20, 1977	614	91	J.F. Kennedy; New York
July 18, 1977	1021	133	J.F. Kennedy; New York

TABLE II
FLIGHT TEST DATA OF JT9D-7A(SP) NO. 1 AND NO. 2 ENGINES ON N536PA AIRCRAFT

Date	Hours	Cycles
May 4, 1977	10	5
May 6, 1977	14	10
May 10, 1977	18	11
May 16, 1977	110	19
May 20, 1977	155	23
June 20, 1977	614	91
July 18, 1977	1021	133

The analyses of the PIC data prior to removing an engine from aircraft N536PA is shown in Figure 3. The deterioration in thrust specific fuel consumption of engines P-695743 and P-695745 was estimated at 1.4 percent and 1.1 percent, respectively. Analysis of the Engine Condition Monitoring data showed a larger difference in deterioration levels between the two engines; 1.5 percent on P-695743 versus 2.5 percent on P-695745.

Deeper fan seal rub was observed on P-695743, and, based on these observations, this engine was selected for removal and returned to Pratt & Whitney Aircraft's JT9D Test Facilities in Middletown to begin a series of systematic tests to assess engine deterioration.

The change in thrust specific fuel consumption previously mentioned for engines P-695743 and P-695745 could not be determined from the PIC data as thrust can not be measured on the wing. An analysis of module deterioration is required from which the change in thrust can be inferred. A performance deterioration modeling activity underway under other tasks of the NASA JT9D Engine Diagnostic Program yielded an improved analysis technique by utilizing a fixed relationship of efficiency and flow capacity losses due to clearance changes for each module. These relationships or pairings provided a reduction of unknowns required to make the determination of module performance losses and therefore estimated thrust loss. Figure 3 presents the results of the analysis of PIC data utilizing this improved technique. The results of the production and experimental testing of engine P-695743, discussed later in this report, showed this analysis to be accurate.

3.2 ENGINE HISTORY

Engine serial number P-695743 was assembled new in Pratt & Whitney Aircraft's Production Assembly Department in Middletown during November 1976 as a JT9D-7A(SP) P/N636900 engine assembly. P-695743 completed its final production acceptance test in test stand No. 4 in Middletown on November 16, 1976. The engine was then packaged and shipped to The Boeing Company for installation in the No. 2 position on B-747(SP) aircraft serial number N536PA. Prior to any flight time on N536PA, P-695743 was calibrated using the PIC system, establishing a performance base line for an installed engine for further deterioration analysis using PIC system data to be analyzed and covered under Task II. There were no incidents on P-695743 up to the time of removal from the aircraft other than an oil tank change after a few flights and prior to delivery to Pan American.

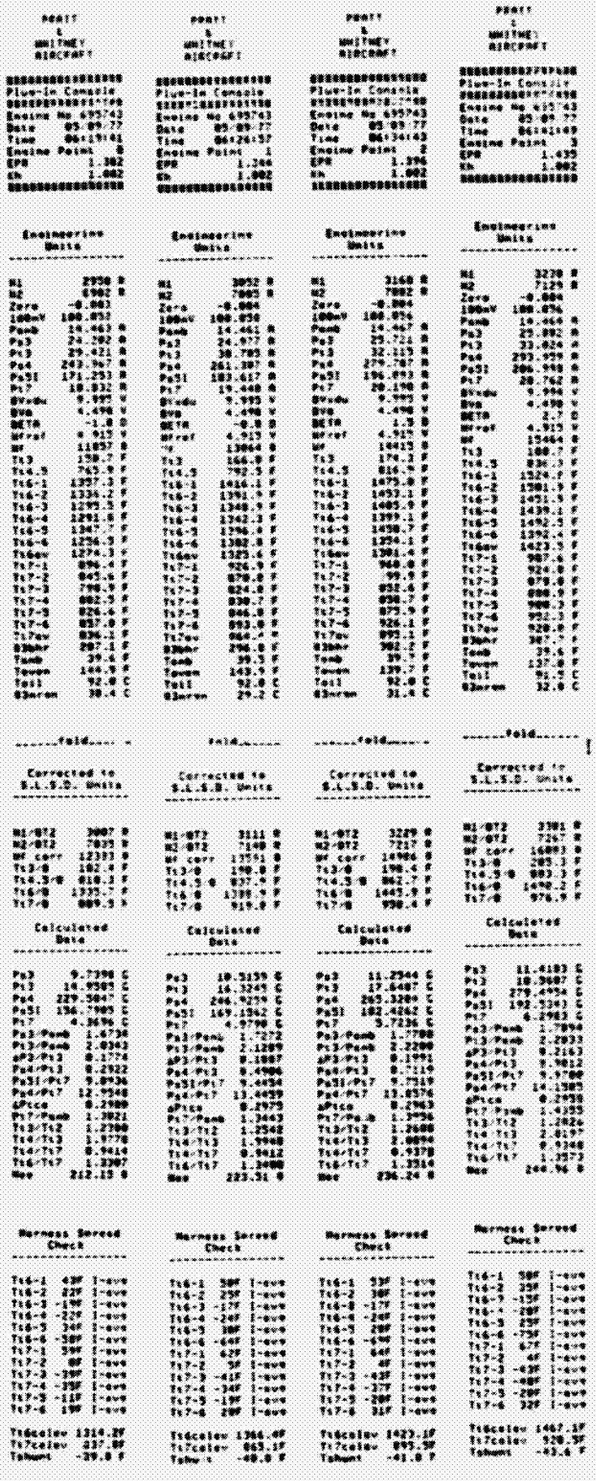
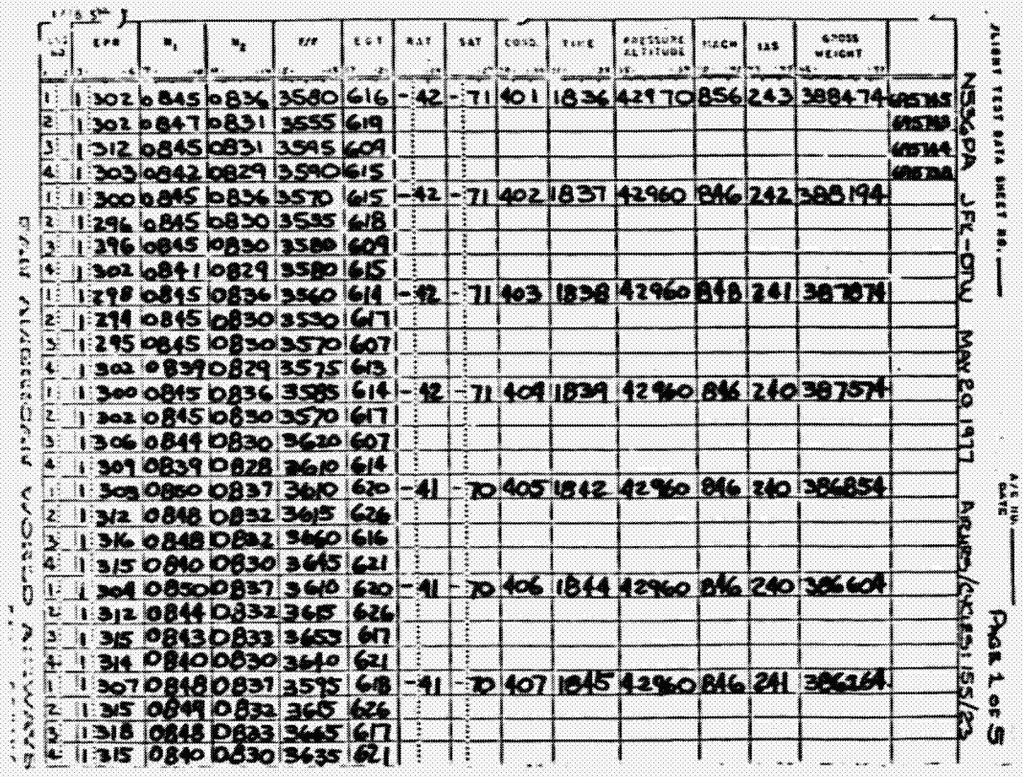


Figure 1 *PIC Test Data – This is a typical printout from the Plug-In Console (PIC) system.*



		EPR	N_1	N_2	FF	EGT	RAT	SAT	COMP.	TIME	PRESSURE ALTITUDE	MACH	IAS	GROSS WEIGHT	
1	1	302	0845	0836	3580	616	-42	-71	401	1836	42970	856	243	388474	615385
2	1	302	0847	0831	3555	619									615389
3	1	312	0845	0831	3595	609									615344
4	1	303	0842	0829	3590	615									615398
1	1	300	0845	0836	3570	615	-42	-71	402	1837	42960	846	242	388194	
2	1	296	0845	0830	3595	618									
3	1	296	0845	0830	3580	609									
4	1	302	0841	0829	3580	615									
1	1	298	0845	0836	3560	614	-42	-71	403	1838	42960	848	241	387874	
2	1	294	0845	0830	3590	617									
3	1	295	0845	0830	3570	607									
4	1	302	0839	0829	3575	613									
1	1	300	0845	0836	3585	614	-42	-71	404	1839	42960	846	240	387574	
2	1	302	0845	0830	3570	617									
3	1	306	0849	0830	3620	607									
4	1	309	0839	0828	3610	614									
1	1	309	0850	0837	3610	620	-41	-70	405	1842	42960	846	240	386854	
2	1	312	0848	0832	3615	626									
3	1	316	0848	0832	3660	616									
4	1	315	0840	0830	3665	621									
1	1	304	0850	0837	3610	620	-41	-70	406	1844	42960	846	240	386604	
2	1	312	0844	0832	3615	626									
3	1	315	0843	0833	3653	617									
4	1	314	0840	0830	3640	621									
1	1	307	0848	0831	3595	618	-41	-70	407	1845	42960	846	241	386264	
2	1	315	0849	0832	3605	626									
3	1	318	0848	0823	3665	617									
4	1	315	0840	0830	3635	621									

Figure 2 Flight Data Acquisition – This is a typical log from flight data test.

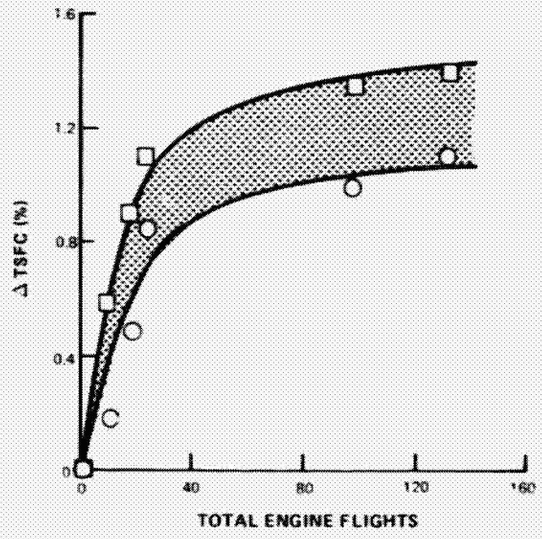


Figure 3 PIC Data Analysis – Results of detailed analysis and trend of short term deterioration.

SECTION 4.0

OVERALL ENGINE PERFORMANCE TEST RESULTS

4.1 INTRODUCTION

The test engine, P-695743, was calibrated in the production test stand to establish the overall engine performance deterioration since new. An "as-received" calibration was run to permit comparison of overall performance changes and parameter shifts with production data taken at Pratt & Whitney Aircraft prior to shipment of the engine to Boeing for installation. The engine was water and detergent washed to remove accumulated surface dirt on gas-path parts and to evaluate the effectiveness of each procedure in restoring performance. The after detergent wash performance levels establish the level of TSFC deterioration from cumulative mechanical damage causes. These performance data, however, did not permit sufficiently accurate assessment of the distribution of performance losses at the module/component level, and testing with experimental engine cases and instrumentation was conducted to determine the distribution of performance losses at the module level.

4.2 PRODUCTION TEST STAND EVALUATION

To minimize the effect of test hardware differences during the evaluation in the production test stand, engine P-695743 was equipped with the same fan ducts and a similar tailpipe, and was installed in the same test stand as was used for the original production acceptance test. Table III presents the sequence of tests in the Middletown production test facility and the resulting changes in thrust specific fuel consumption (ΔTSFC) for each test relative to the production acceptance test. Actual test data are plotted in Figure 4 for each of the tests.

TABLE III
PRODUCTION STAND TEST SEQUENCE

Date	Test Description	ΔTSFC at Take-Off Thrust (%)
Nov. 16, 1976	Production Acceptance Test	Base Line
July 28, 1977	As Received (1081 hours and 141 cycles)	+1.5
July 29, 1977	After Retrim to New Production Engine Vane Control (EVC) Schedule for Engine P-695743	+1.4
Aug. 1, 1977	After Water Wash	+1.2
Aug. 1, 1977	After Retrim to EVC Schedule Prior to Detergent Wash	+1.2
Aug. 2, 1977	After Detergent Wash	+1.2

As received, engine P-695743 had deteriorated +1.5 percent in TSFC at take-off thrust (46,150 pounds). The high-pressure compressor stator vane schedule was low relative to the production acceptance level by approximately 1.5 degrees, and the engine vane control was retrimmed to eliminate any performance change resulting from off-schedule vanes. After retrimming, the as-received level of TSFC was im-

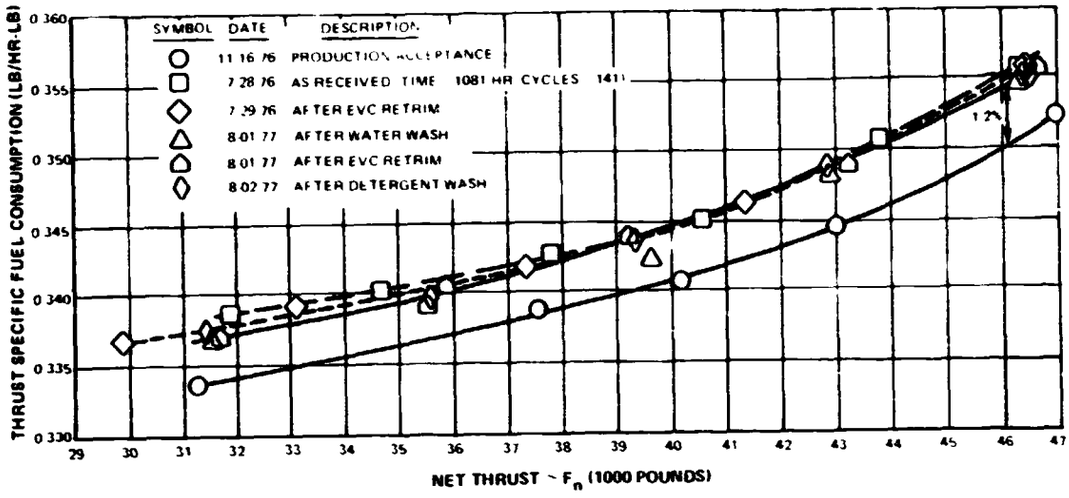


Figure 4 Production Test Stand Calibration – Test results are plotted for each of the tests defined in Table III.

proved by -0.1 percent due to an estimated +0.15 point improvement in high-pressure compressor efficiency. Engine P-695743 was then water washed to remove any effects resulting from contamination of the flow path by dirt, grease, etc.

The water wash improved engine TSFC by another -0.2 percent, due primarily to a +0.3 point improvement in high-pressure compressor efficiency. Another slight adjustment to the vane schedule and a subsequent detergent wash resulted in no further TSFC improvement. In summary, the level of TSFC after removing the effects of gas-path contamination and off-schedule vanes was +1.2 percent relative to the production acceptance test level.

Production engines are not designed for extensive performance instrumentation because this capability is not required for the monitoring of engine performance in revenue service. Consequently, capability for measuring a number of pressures and temperatures, required for accurate analysis of engine module performance, is provided at single points (T_{t3}, T_{t4}, P_b) or by single averaging rakes (four point average for P_{t3}) at one circumferential location in the gas path during the production test stand evaluation. Changes in clearances of mechanical part condition are likely to produce changes in radial and/or circumferential flow profiles. Thus, the accuracy of these measured values are suspect as to the degree to which they represent true average gas-path pressure or temperature conditions. In addition, fan exit temperature and pressure and high-pressure turbine exit pressure are not measured. These parameters are required to accurately determine changes in fan, high-pressure turbine, and low-pressure turbine performance.

Performance engineers have developed a comprehensive analysis technique to estimate engine module performance changes from engine test data. This technique utilizes influence coefficients which relate module efficiency and flow capacity to various measured gas generator performance parameters as theoretically derived from a computer simulation of the JT9D-7 engine at sea level take-off conditions. Since all of the parameters for determining efficiency and flow capacity loss were not directly measured during this test, various

combinations of module loss estimates were evaluated. The evaluation was iterated until the summation of all of the estimates of module losses produced changes in measurable parameters that agreed reasonably well with the measured parameter changes.

The gas generator data from the last production calibration of engine P-695743 were compared to the original production acceptance test data, and the results of the comprehensive analysis discussed above are presented in Table IV. This table compares the measured parameter changes with the calculated changes in these parameters that would occur in an average new engine using the analytically determined module performance losses which are listed in Table V. Table V also presents the distribution of the equivalent change in TSFC for each module.

It can be noted that this analysis indicates that most of the deterioration is in the turbine section (0.8 percent TSFC)with relatively little in the fan and compressor section (0.24 percent TSFC). The results also indicate that a large part of the deterioration is in the low-pressure spool (fan + low-pressure compressor + low-pressure turbine = 0.74 percent TSFC) and a lesser amount in the high-pressure spool (high-pressure compressor + high-pressure turbine = 0.3 percent TSFC).

TABLE IV

GAS GENERATOR ANALYSIS
POST DETERGENT WASH DATA RELATIVE TO PRODUCTION ACCEPTANCE

Parameter	Measured Parameter Change (% or °F)	Calculated Parameter Change (% or °F) Based on Estimated Module Changes
Measured at Constant F_n:		
TSFC	+ 1.2	+ 1.04
Measured at Constant EPR:		
F_n/δ_{T2}*	- 0.8	- 0.5
W_f*	+ 0.4	+ 0.5
N_1*	+ 0.1	0
N_2*	- 0.1	- 0.15
W_{AT}*	- 0.3	- 0.3
P_{T3}/P_{T2}	0	+ 0.1
P_b/P_{T3}	- 0.75	- 0.85
P_b/P_{T7}	- 0.75	- 0.75
T_{T3}*	+ 1°F	+ 1°F
T_{T4}*	- 2°F	- 4°F
T_{T5}*	+ 3°F	+ 8°F
T_{T6}*	+15°F	+10°F
T_{T7}*	- 2°F	+10°F
Other Parameters		
Fan Flow Capacity	- 0.3	- 0.3
Low-Pressure Compressor Flow Capacity	- 0.3	- 0.3

* Corrected to Station 2.0 Conditions.

TABLE V

SUMMARY OF EQUIVALENT MODULE DETERIORATION
BASED ON INFLUENCE COEFFICIENT ANALYSIS

Parameter	Estimated Module Parameter Change (%)	Equivalent Change in TSFC (%)
Fan:		
Efficiency	- 0.25	+0.19
Flow Capacity	- 0.30	- 0.04
Low-Pressure Compressor:		
Efficiency	- 0.25	+0.09
Flow Capacity	- 0.30	0
High-Pressure Compressor:		
Efficiency	0	0
Flow Capacity	0	0
High-Pressure Turbine:		
Efficiency	- 0.35	+0.23
Flow Capacity	+ 0.50	+0.07
Low-Pressure Turbine:		
Efficiency	- 0.50	+0.50
Flow Capacity	0	0
	Total =	+1.04
	Measured =	+1.20

4.3 EXPERIMENTAL TEST STAND EVALUATION

In order to evaluate component performance levels more accurately, the engine was partially disassembled to permit the installation of special experimental engine cases and an expanded instrumentation package. During reassembly, special attention was given to maintaining the clearances at their disassembly value during installation of the experimental cases. The installed expanded instrumentation permitted a direct means of measuring average temperature and pressure conditions and profile effects from which component performance could be directly calculated. After installation of the experimental cases and expanded instrumentation, the engine was prepared for testing in an experimental test stand.

The test was conducted in X-8 test stand at Pratt & Whitney Aircraft's East Hartford Engineering test facilities and consisted of a ten-point calibration. Using data from the expanded instrumentation testing, efficiencies were calculated for the fan, low-, and high-pressure compressors, and high- and low-pressure turbines. The efficiency level for each module was determined from these data at sea level take-off engine pressure ratio.

Component efficiency levels were not measured during production acceptance testing of

engine P-695743. Therefore, the calculated component efficiency levels were compared to experimental and production test data from other engines and component rig tests which represent the average new production component performance definitions in the design system. The comparison is indirect, however, it represents the only type of comparison that could be undertaken to accomplish an improved assessment of the component efficiency losses that occurred during operational usage.

Data from low-pressure turbine rig testing was used to establish low-pressure turbine performance deterioration. In order to compare engine data to rig data, the engine data for the low-pressure turbine must be corrected to remove the effect of the turbine exit case strut loss that is sensed by the P_{T7} probes. Rig component efficiencies which form the base line are based on performance data measured upstream of the struts. The correction increases low-pressure turbine efficiency by 0.5 point.

An additional correction was applied to high-pressure compressor and turbine efficiencies to account for a difference in the trim of the stator vane schedule (SVS) between the experimental calibration of P-695743 and the base line. Examination of the variable vane schedule versus corrected high-pressure spool speed showed the vane schedule during the calibration to be closed relative to that of the base line. The test engine calibration data, therefore, was analytically adjusted for vane schedule using a correction curve based on a combination of rig and engine vane schedule experience. This correction increased high-pressure compressor efficiency by 0.8 point and lowered high-pressure turbine efficiency by 0.5 point.

The module losses developed by comparing the adjusted P-695743 module efficiency levels with the design system production acceptance test base line levels are presented in Table VI. The summation of the individual module ΔTSFC's of 1.19 percent agrees very closely with the measured production test stand data (1.2 percent). This analysis indicates that the low-pressure compressor and the high-pressure turbine are the principal contributors to the overall engine deterioration. Additionally, the results show that the losses are about equally split between the high- and low-pressure spools as well as between the hot and cold section components of the engine.

A comparison of the production test results and the experimental test program on P-695743 are shown in Table VII.

The analysis of the experimental data, when compared to the production data analysis, results in a redistribution of losses in the low-pressure spool from low-pressure turbine to low-pressure compressor and the somewhat higher measured losses in the high-pressure turbine. Section 5.0 discusses and compares the module performance loss assessment based on experimental testing with those obtained from the inspection and analysis of part condition and clearances obtained during the analytical teardown of engine P-695743.

TABLE VI

RESULTS OF CALIBRATION IN EXPERIMENTAL TEST STAND

Component	Δ Efficiency (*)	%Δ TSFC/Δ Efficiency	Δ TSFC (%)
Fan	-0.2	-0.77	+0.15
Low-Pressure Compressor	-1.0	-0.35	+0.35
High-Pressure Compressor	-0.2	-0.59	+0.12**
High-Pressure Turbine	-0.7	-0.67	+0.47**
Low-Pressure Turbine	-0.1	-0.99	+0.10***
		Total	+1.19%
		Measured ΔTSFC (Production)	+1.2%

* Relative to Production Acceptance Test

** Adjusted for HPC SVS Differences

*** Corrected for Turbine Exit Case Strut Loss

TABLE VII
COMPARISON OF PRODUCTION TEST AND EXPERIMENTAL TEST RESULTS

Component	Estimated Efficiency Change (%) Production Test	Estimated Efficiency Change (%) Experimental Test
Fan	−0.25	−0.20
Low-Pressure Compressor	−0.25	−1.00
High-Pressure Compressor	0	−0.20
High-Pressure Turbine	−0.35	−0.70
Low-Pressure Turbine	−0.50	−0.10

SECTION 5.0

MODULE/COMPONENT TEST RESULTS

5.1 FAN

During P-695743 engine testing using expanded instrumentation, fan efficiency was calculated (as previously discussed in Section 4.0) at each operating point and plotted to establish the operating line and a value at an engine pressure ratio level corresponding to take-off power. Figure 5 shows the fan operating line for all of the calibration points. The comparison of this level with the level of fan efficiency for an engine after production acceptance test established that the fan had lost 0.2 point in efficiency over the time period of service of engine P-695743. On this basis, the measured short-term efficiency deterioration in the fan module of engine P-695743 is estimated as 0.2 point.

Analytical Teardown

During the analytical teardown and inspection, the fan module was found to be in generally excellent condition. Measurements of fan tip clearance, rub-strip depth, airfoil surface roughness, blade length, etc., as well as visual observation of the parts condition, were made.

Outer Air Seal Clearances

The average blade tip clearance over the top half of the engine, shown in Figure 6, was measured prior to the initial teardown as 0.136 in. The Bill-of-Materials nominal tip clearance is 0.120 in. and the average engine after production acceptance test has negligible fan rubs. This information leads to the conclusion that the engine fan tip clearance had increased +0.016 inch since its production acceptance test. Fan rub-strip rub depths were also measured during the teardown. These measurements are shown in Figure 7. The effect of the 0.065 inch rub-strip offset grind on the bottom quarter of the engine has been factored out of these measurements. The average rub in the upper half of the engine was 0.030 inch, higher than the 0.016 inch calculated tip clearance change. However, fan rub depth measurements are considered a less accurate indicator of tip clearance.

It should be noted that the rub-strip installed by P&WA, a 0.115 inch offset configuration, was removed at Boeing and replaced with a 0.065 inch offset configuration prior to the first flight.

Approximately 40 percent of the blade tips had indications of rubbing on the fan outer air seal. Figure 8 shows both rubbed and rub-free blade tips. The fan case outer air seal was in excellent condition with the expected blade rub paths around the entire circumference. Figure 9 shows a typical blade rub path on the outer air seal.

Measurements document a blade tip clearance change of +0.016 in. in engine P-695743. Rig testing has shown that for a blade the size of the JT9D-7 fan, +0.016 in. additional tip clearance will penalize fan efficiency by -0.15 point.

Roughness

Fan blade surface roughness was measured as 45 AA* (microinches); new parts have a roughness of 32 AA*. This surface roughness increase, combined with the fan work level, sea level take-off Reynolds Number, and nominal fan loss level was run through the compressor design system to show that a loss of 0.1 point in fan efficiency will result.

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* Arithmetic average

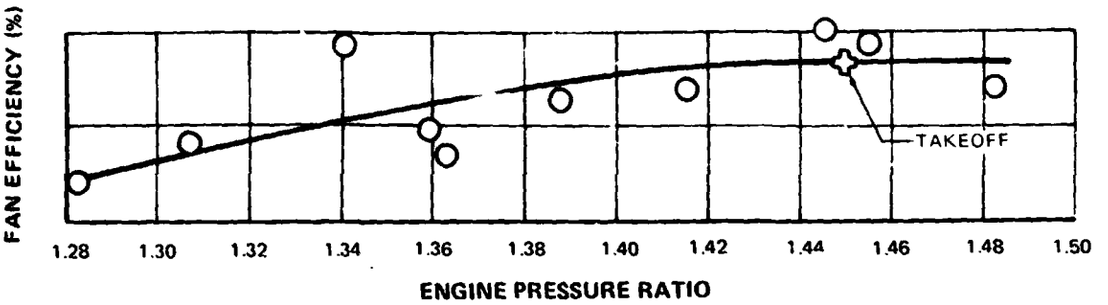


Figure 5 *Fan Module Performance – Efficiency date comparison indicated a loss of 0.? point in efficiency for the fan.*

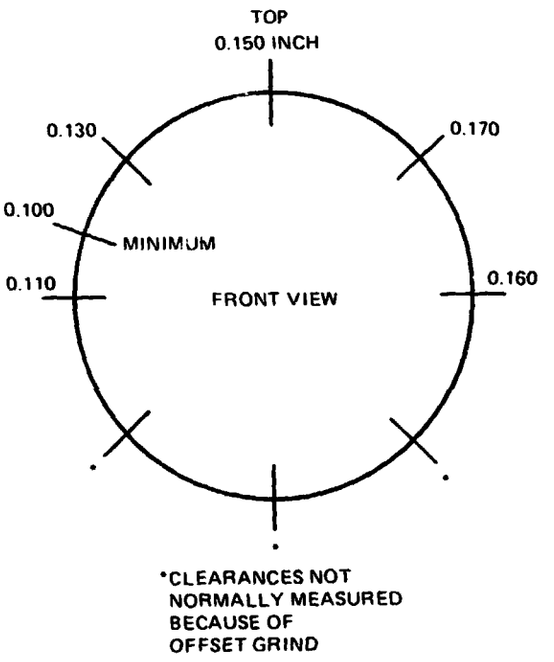


Figure 6 *"As-Received" Fan Blade Tip Clearance Measurements – The average clearance prior to teardown was 0.136 in.*

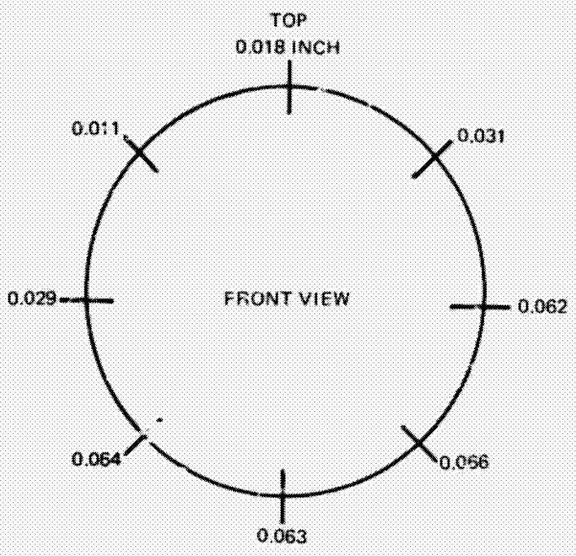


Figure 7 *Fan Outer Case Rub-Strip Rub Depth Measurements – Offset grind of 0.065 inch has been factored out of measurements.*

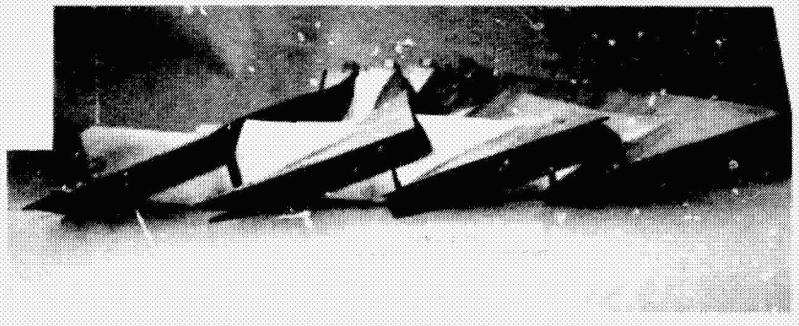


Figure 8 *Range of Fan Blade Tip Rubbing – Blades on the left did not rub; blades on the right show evidence of heavy rubbing. (77-444-0254-C)*

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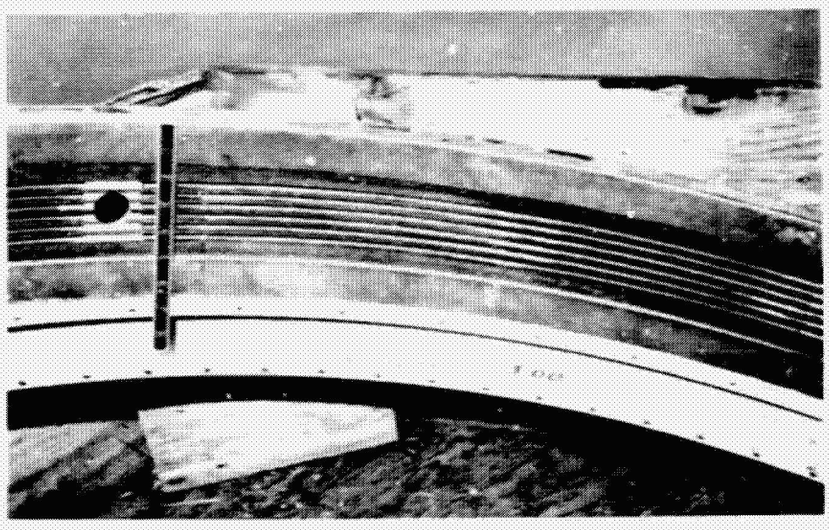


Figure 9 Fan Case Seal Rubbing — Typical blade rub path on the outer air seal. (77-444-0254-A)

Other Physical Conditions

Three fan blades were found with very minor leading edge nicks. The blade platform seals, shown in Figure 10, were all found to be in good condition, with none missing, loose or torn. The fan exit guide vanes were exceptionally clean and in excellent condition, as shown in Figure 11. Two vanes were received with a very minor leading edge blend on each vane. There was no visible flow-path hardware durability damage that would account for any additional performance deterioration.

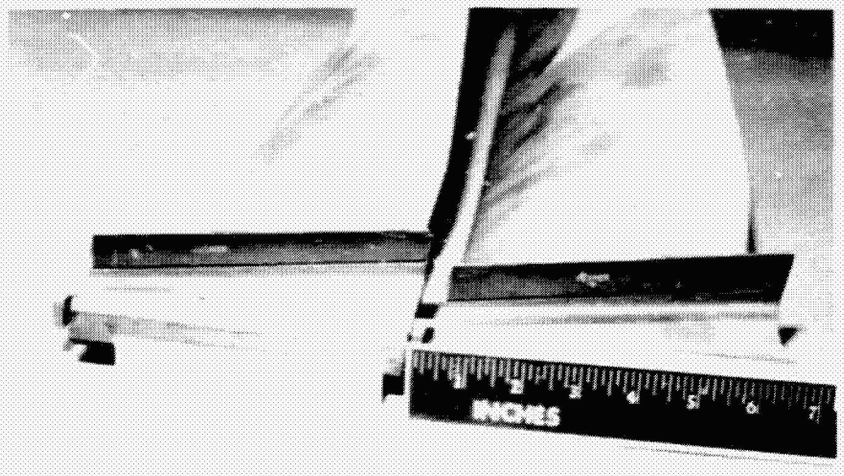


Figure 10 Fan Blade Platform Seals — All platform seals were found to be in good condition.

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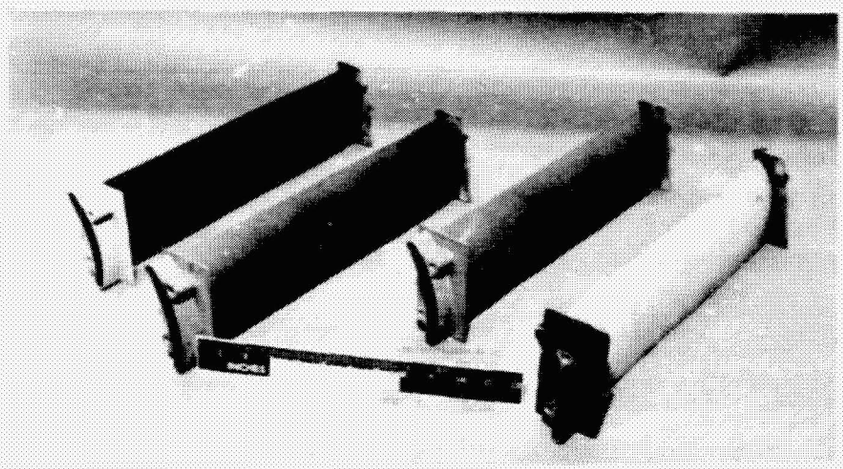


Figure 11 Typical Fan Exit Guide Vanes – Vanes were in excellent condition and exceptionally clean. (77-444-0254-AE)

Summary

Summary tabulations of fan efficiency loss are shown in Table VIII.

TABLE VIII

SUMMARY OF FAN EFFICIENCY LOSS

EXPERIMENTAL TEST RESULTS

Module	ΔEff. (%)	ΔTSFC / ΔEff.	ΔTSFC(%)
Fan	-0.2	-0.77	+0.15

ANALYTICAL TEARDOWN RESULTS

Efficiency Loss		
Airfoil Roughness	Tip Clearance	Equivalent ΔTSFC(%)
-0.10 point	-0.15 point	+0.19

5.2 LOW-PRESSURE COMPRESSOR

During P-695743 engine testing using expanded instrumentation, low-pressure compressor efficiency was calculated, plotted, and established for an engine pressure ratio level corresponding to take-off power. Figure 12 shows the operating line of low-pressure compressor efficiency for all of the calibration points. The low-pressure compressor efficiency level for an average engine after production acceptance test at take-off engine pressure ratio was used as the basis for comparison. On this basis, the measured short-term efficiency deterioration in the low-pressure compressor module is estimated as 1.0 point.

Analytical Teardown

During the analytical teardown and inspection, the low-pressure compressor module was found to be in generally good condition except for the erosion and rub of the rubber seal material in all low-pressure compressor outer air seals as shown typically on Figure 13. Measurements of the low-pressure compressor blade clearance, blade length, rub depth, rub circumferential location, airfoil surface roughness, and inner seal rubs, as well as visual observation of the parts condition, were

made. Blade-length measurements were within blueprint tolerances, and no performance penalty can be associated with this parameter.

Outer Air Seal Clearances

Blade tip clearance measurements by stage are tabulated below relative to baseline average engine clearances measured after production acceptance testing of a number of other engines. Table IX shows an average increase in blade tip clearance of +0.012 in.

Rub depth measurements of the outer rub strips are tabulated below relative to rub depths measured on an average production engine after production acceptance test. Table X shows an average increase in rub depth of +0.013 in.

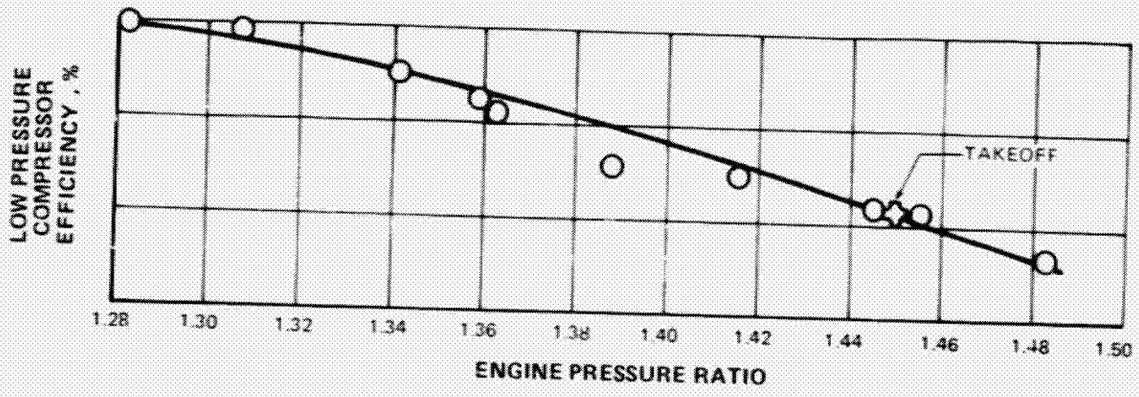


Figure 12 *Low-Pressure Compressor Performance - Efficiency data indicated a loss of 1 point in efficiency for the low-pressure compressor.*

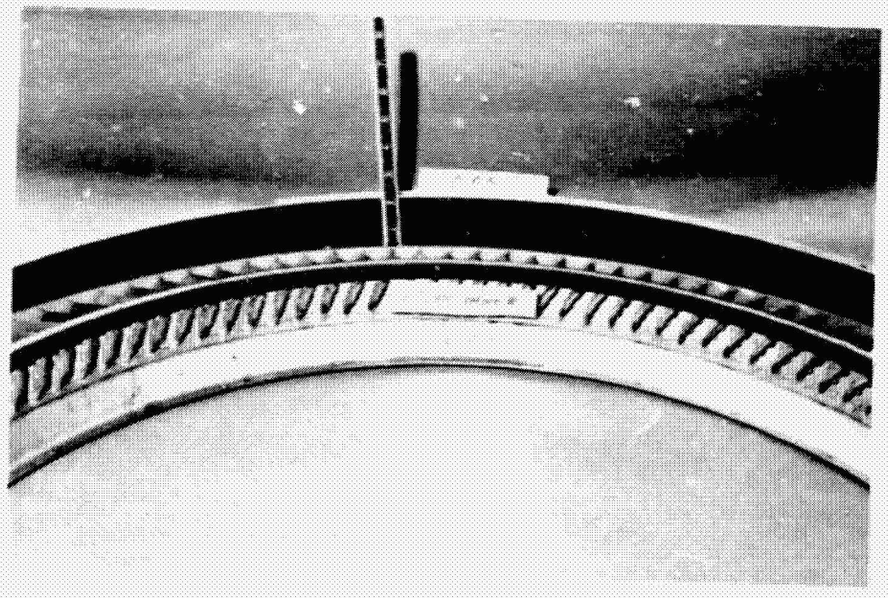


Figure 13 *Fourth-Stage Low-Pressure Compressor Air Seals Erosion of the rubber seal material in the outer air seal occurred. (77-444-0254-F)*

TABLE IX
LOW-PRESSURE COMPRESSOR BLADE TIP CLEARANCE INCREASES

Rotor Number	Measured in Test Engine* (in.)	Change from Post-Prod. Accept. (in.)	Test Engine*: Change from Post-Prod. Accept. (in.)
2	0.075	0.072	+0.003
3	0.027	0.031	-0.004
4	0.091	0.054	+0.037
Avg.	0.064	0.052	+0.012

*P-695743

TABLE X

LOW-PRESSURE COMPRESSOR OUTER AIR SEAL RUB DEPTH INCREASES

Rotor Number	Measured in Test Engine* (in.)	Measured in Post-Prod. Accept. (in.)	Test Engine*: Change from Post-Prod. Accept. (in.)
2	0.016	0.002	+0.014
3	0.006	0.002	+0.004
4	0.027	0.004	+0.023
Avg.	0.016	0.003	+0.013

*P-695743

Tip clearance and rub depth measurements agree on the average, showing a 0.012 to 0.013 in. tip clearance increase relative to the average production acceptance engine. The distribution of the tip clearance change, as measured by the two methods agree well; however, the rub-strip rub depth method is considered the most reliable.

Compressor rig testing has shown that a 0.013 in. increase in tip clearance will penalize low-pressure compressor efficiency by -0.6 point.

Inner Air Seal Clearances

Measurements of the inner air seal rub depths are shown in Table XI relative to rub depths measured after the production acceptance test.

Changes in the inner air seal rub depths are minimal and are considered to have had a negligible impact on the measured performance deterioration.

The circumferential locations of the rubs and rub depths on the inner and outer air seals in the low-pressure compressor were documented and are shown in Figures 14, 15, 16.

TABLE XI

LOW-PRESSURE COMPRESSOR INNER AIR SEAL RUB DEPTH INCREASES

Stator Number	Measured in Test Engine* (in.)	Measured in Post-Prod. Accept. (in.)	Test Engine*; Change from Post-Prod. Accept. (in.)
2	0.004	0.002	+0.002
3	0.005	0.000	+0.005
4	0.007	0.003	+0.004
Avg.	0.005	0.002	+0.004

*P-695743

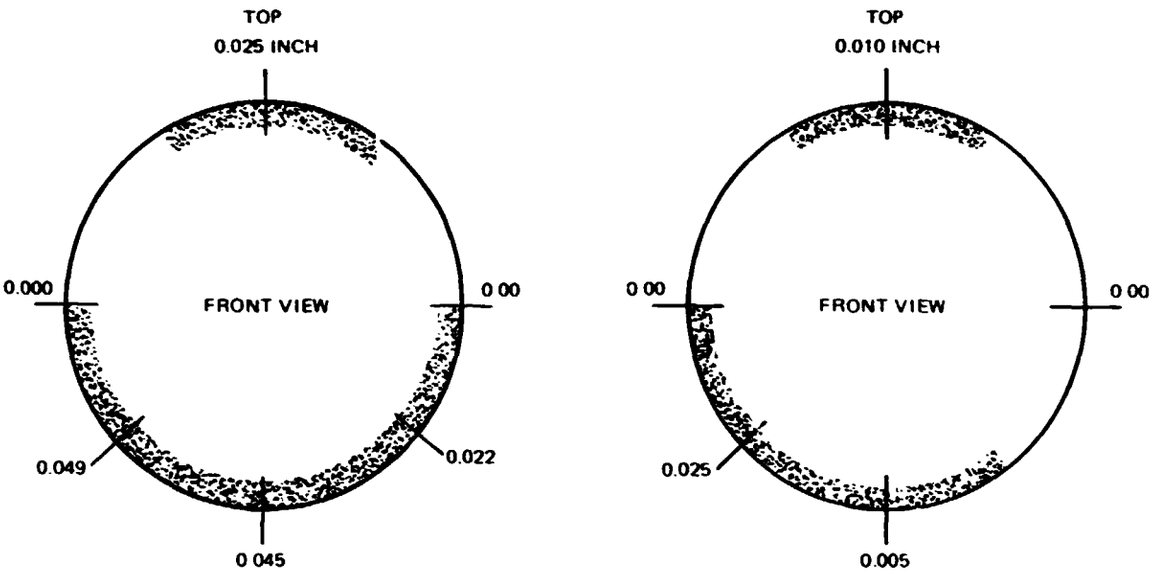


Figure 14 *Second-Stage Compressor Seal Centrifugal Rub Location and Depth Documentation Rub of the outer air seal (left) is shown to be light to moderate and of the inner air seal (right) is also light to moderate.*

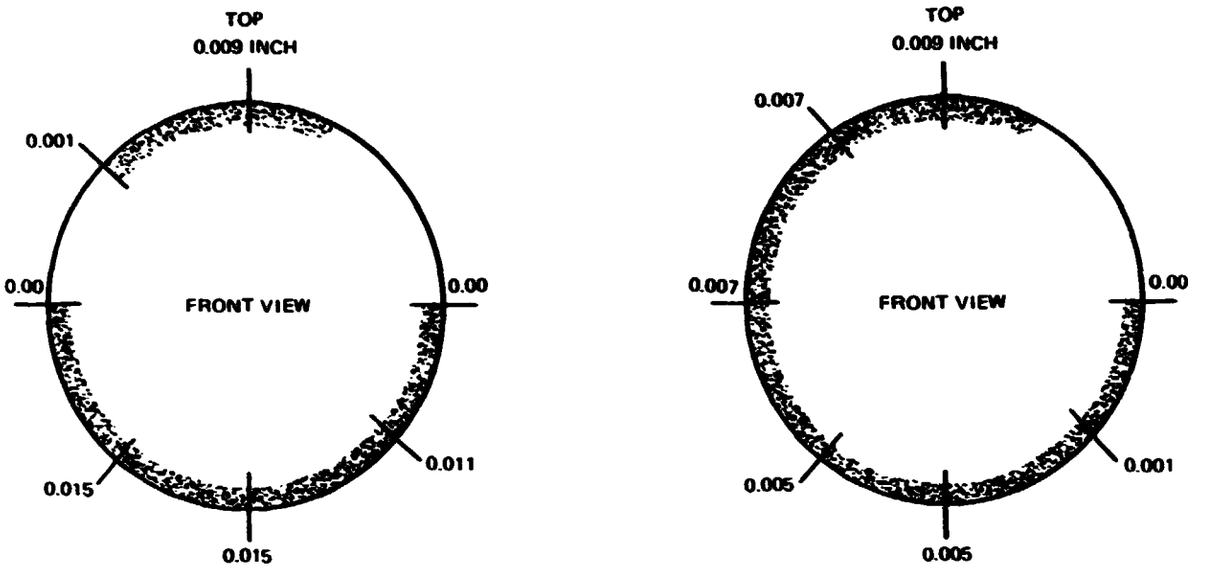


Figure 15 *Third-Stage Compressor Seal Centrifugal Rub Location and Depth Documentation – Rub of the outer air seal (left) is shown to be moderate and of the inner air seal (right) is also moderate.*

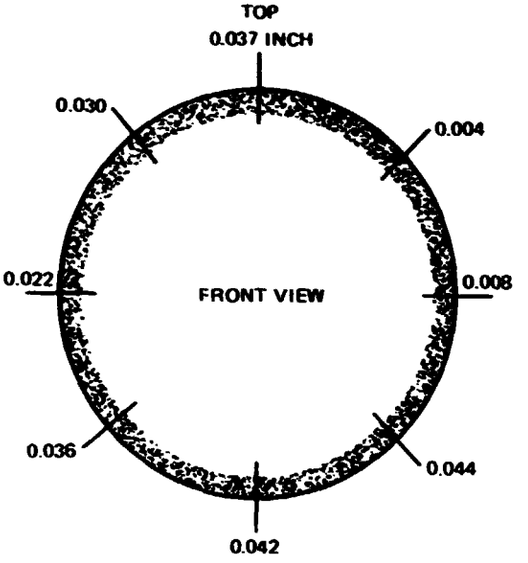


Figure 16 *Fourth-Stage Compressor Seal Centrifugal Rub Location and Depth Documentation – Rub of the outer air seal is shown to be heavy.*

Roughness

Airfoil surface roughness was measured as 36 AA or a slight increase relative to the 32 AA value for new parts. There were indications of dirt on both surfaces of the airfoils which is reflected in the surface roughness measurements. The performance impact, as determined by the compressor design system, resulting from this increase in roughness was assessed to cause an efficiency decrease of 0.1 point in the low-pressure compressor.

Overall Physical Condition

Typical photographs of the low-pressure compressor blades, stators, and inner and outer air seals are shown in Appendix G. The airfoils appeared to be like new with no indications of Foreign Object Damage (FOD) or erosion.

All blade root sealant was in excellent condition. The 3.0 bleed system, which provides for low-pressure compressor stability margin during off-design operation, was functionally inspected, and no discrepancies or signs of leakage were found. The bolts on the case flanges were tight and flanges were properly sealed.

Summary

A summary tabulation of low-pressure compressor efficiency loss is shown in Table XII.

5.3 HIGH-PRESSURE COMPRESSOR

During P-695743 engine testing using expanded instrumentation, high-pressure compressor efficiency was calculated, plotted and estimated for an engine pressure ratio corresponding to take-off power. Figure 17 shows the high-pressure compressor efficiency levels for all of the calibration points along with the adjusted efficiency level at sea level take-off.

High-pressure compressor efficiency level for an average engine after production acceptance test was used for comparison and the measured short-term efficiency deterioration in the high-pressure compressor module was initially estimated as -0.2 point.

TABLE XII
SUMMARY OF LOW-PRESSURE COMPRESSOR EFFICIENCY LOSSES

EXPERIMENTAL TEST RESULTS

Module	Δ Eff. (%)	$\frac{\Delta TSFC}{\Delta Eff.}$	Δ TSFC (%)
Low-Pressure Compressor	-1.0	-0.35	+0.35

ANALYTICAL TEARDOWN RESULTS

Efficiency Loss			
Airfoil Roughness	Tip Clearance	Δ Eff. (%)	Equivalent Δ TSFC (%)
-0.1 point	-0.6 point	-0.7	+0.25

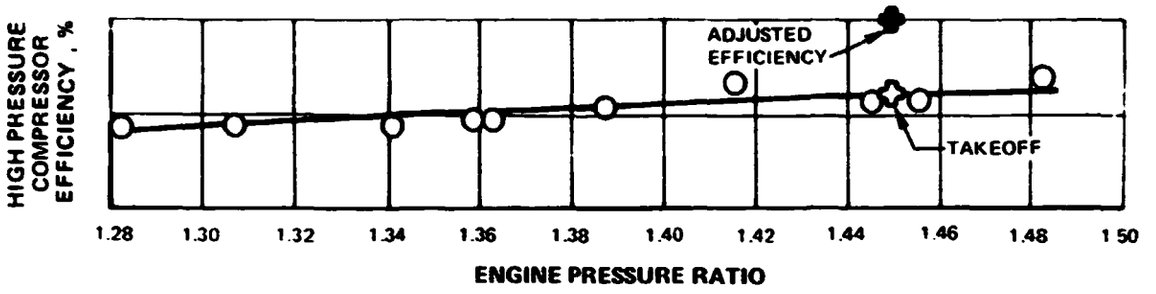


Figure 17 *High-Pressure Compressor Performance – Efficiency data indicated a loss of 0.2 point in efficiency for the high-pressure compressor.*

The indicated adjustment to high-pressure compressor efficiency was based on an examination of the stator vane schedule as a function of corrected high-pressure rotor speed, which indicated that the vanes were closed relative to those of an average production engine. The measured parameters were adjusted to reflect the vane closure based on correction curves developed from rig and engine vane schedule experience.

Analytical Teardown Results

During the analytical teardown and inspection, the high-pressure compressor was found to be in excellent overall condition. Measurements of the high-pressure compressor blade tip clearance, blade length, rub-strip rub depth, rub location, inner air seal rubs, airfoil surface roughness, etc., as well as visual observation of the parts condition, were made. Blade length measurements showed the blades to be within blueprint tolerances with the exception of the 12th.-stage blades which were 0.005 in. under the blueprint minimum length. The penalty for blade-length change was judged to be immeasureable.

Outer Air Seal Clearances

Blade tip clearance measurements by stage are shown in Figure 18 relative to clearances for the average JT9D-7 after the production acceptance test. As shown on the figure, the P-695743 engine clearances appear, on the average, to be tighter by 0.003 in. than that for the average JT9D-7 after the production acceptance test.

Measurements of outer rub-strip rub depth data are shown in Figure 19. These measurements show that engine P-695743 blade tip clearances had increased by 0.004 in. relative to the average JT9D-7 after the production acceptance test.

These two methods of establishing blade tip clearance (direct measurement of clearance and measurement of rub-strip rub depth) were analyzed, and it is concluded that the tip clearance in the high-pressure compressor of engine P-695743 increased from 0.0 to 0.004 in. The two clearance values were averaged to yield a tip clearance change of 0.002 in. relative to an average production JT9D-7 engine after production acceptance test. Compressor rig testing has shown that a 0.002 in. increase in the tip clearance will penalize high-pressure compressor efficiency by -0.2 point.

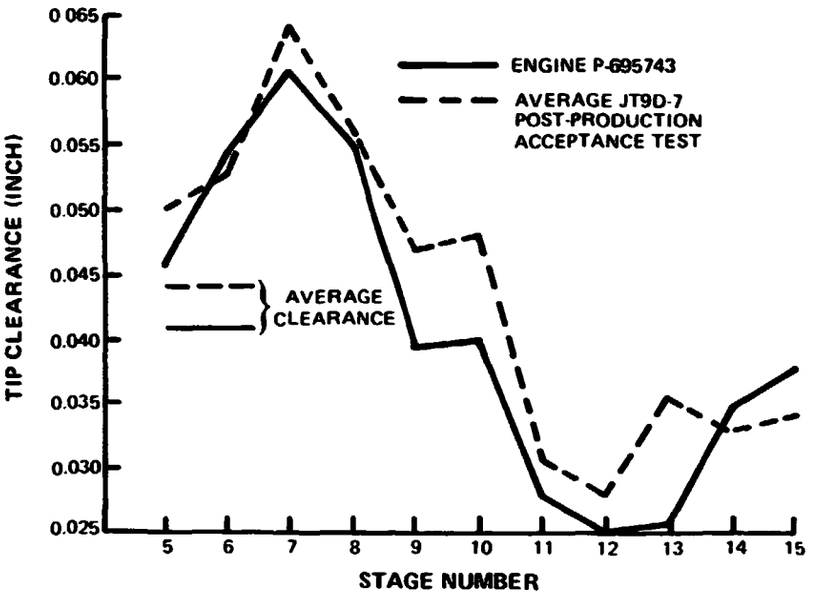


Figure 18 *Documentation by Stage of High-Pressure Compressor Blade Tip Clearance – On the average, the test engine clearance is tighter than that for the average JT9D-7 engine after the production acceptance test.*

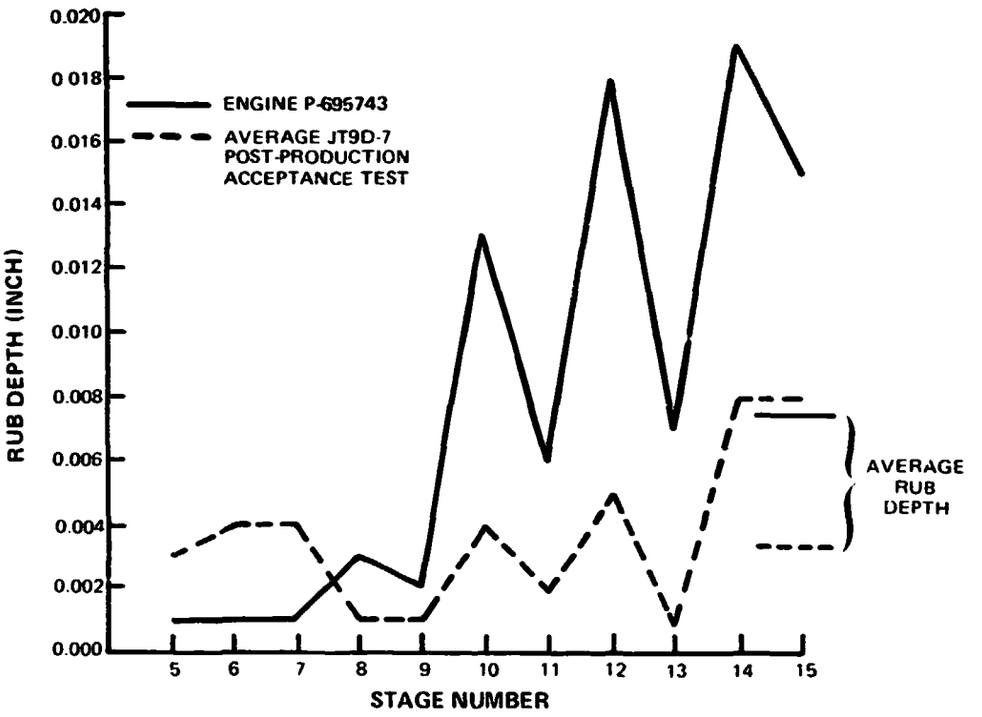


Figure 19 *Documentation by Stage of High-Pressure Compressor Rub-Strip Rub Depth These measurements show that the test engine tip clearance had increased by 0.004 in. relative to the average JT9D-7 engine after the production acceptance test.*

Inner Air Seal Clearances

Table XIII compares blade tip clearance based on measurements of radial groove depths in the inner air seal for the test engine and engines after production acceptance tests. On the average, the overall groove depth change was 0.001 in. greater on engine P-695743, and this change was judged to have a negligible impact on measured performance deterioration.

The circumferential locations of the rubs and rub depths on the inner and outer air seals in the high-pressure compressor were documented and are shown in Figure 20 through 30.

TABLE XIII

RADIAL GROOVE DEPTHS IN THE INNER AIR SEAL

Stage Number	Avg. Groove Depth (in.) in New Production Green-Run Engines	Avg. Groove Depth (in.) in Test Engine*
5 to 6	0.007	0.007
6 to 7	0.011	0.003
7 to 8	0.003	0.005
8 to 9	0.003	0.003
9 to 10	0.004	0.004
10 to 11	0.004	0.005
11 to 12	0.004	0.004
12 to 13	0.002	0.001
13 to 14	0.003	0.016
14 to 15	0.011	0.015

*P-695743

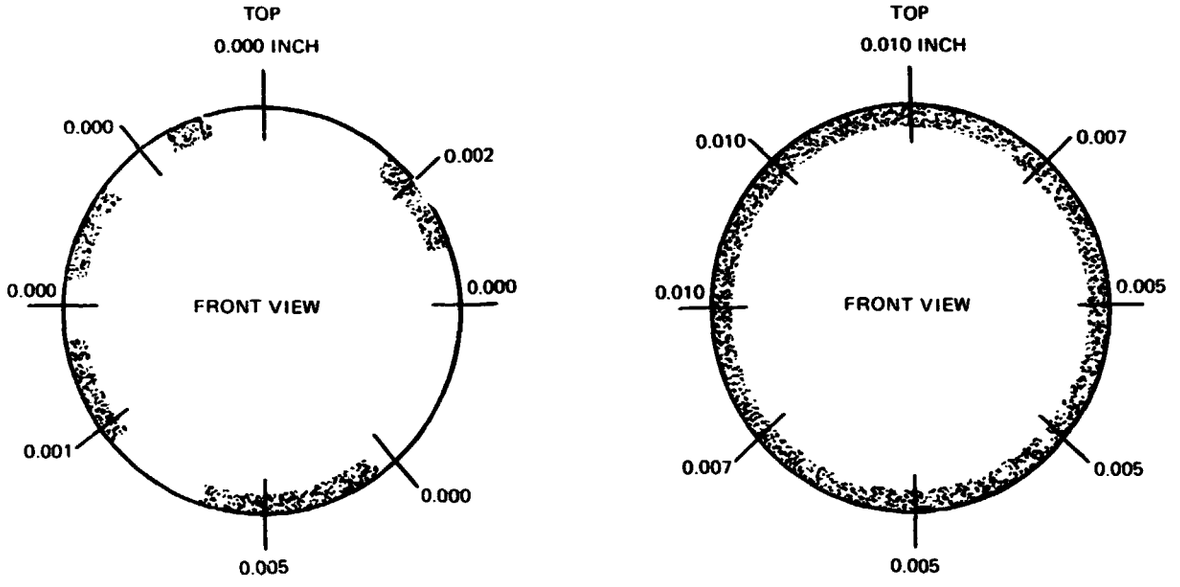


Figure 20 *Fifth Stage Compressor Seal Circumferential Rub Location and Depth Documentation - Rub of the outer air seal (left) is shown to be light and in isolated areas, and knife edge grooving of the inner air seal (right) is shown to be light to moderate.*

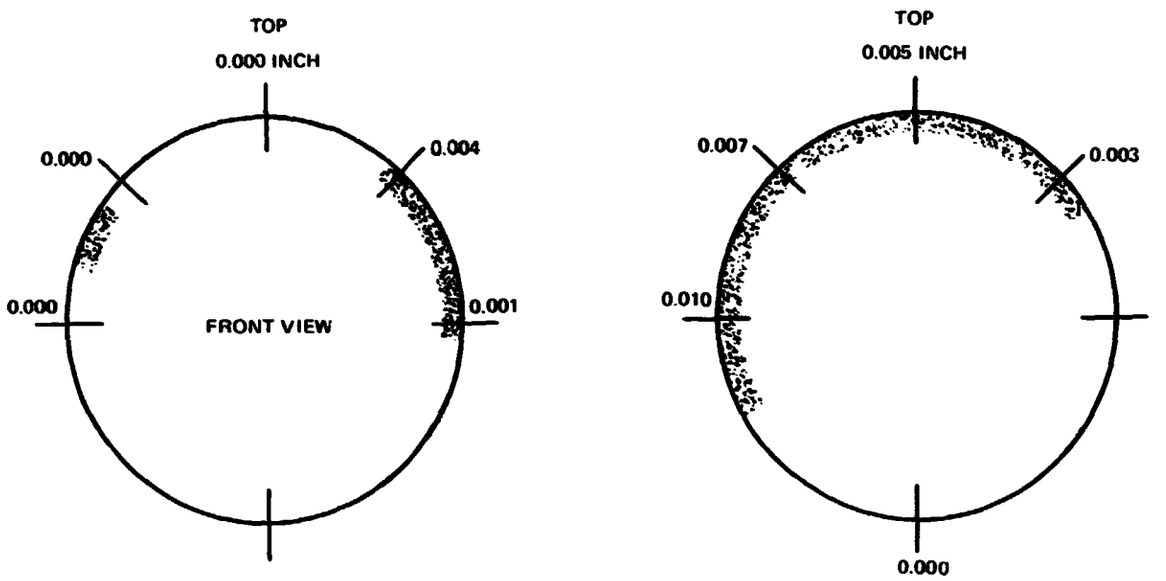


Figure 21 *Sixth-Stage Compressor Seal Circumferential Rub Location and Depth Documentation – Rub of the outer air seal (left) is shown to be light and in isolated areas, and knife edge grooving of the inner air seal (right) is shown to be light.*

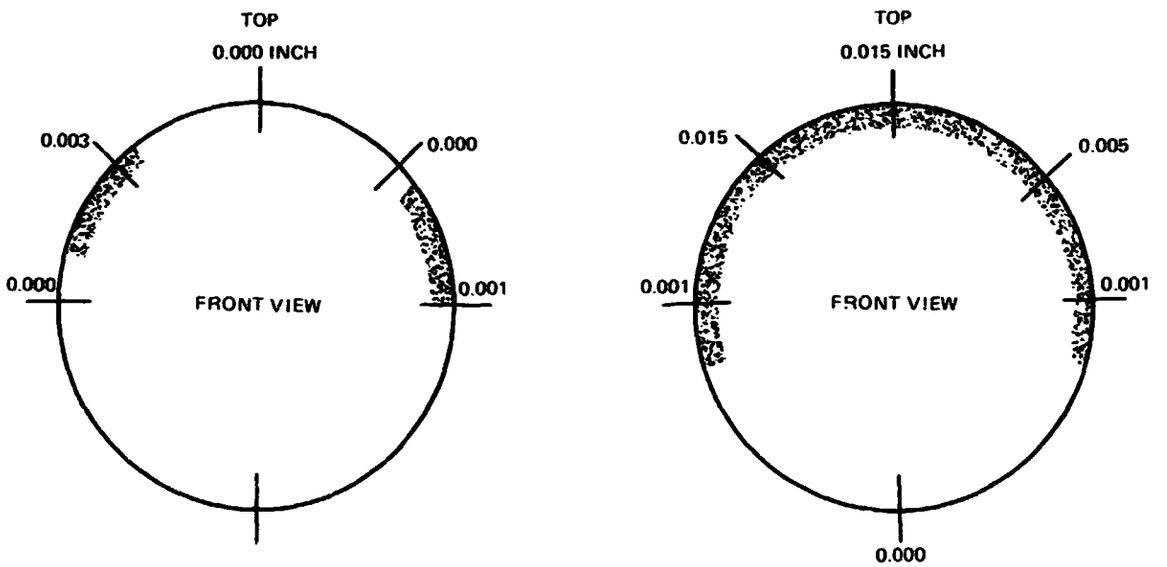


Figure 22 *Seventh-Stage Compressor Seal Circumferential Rub Location and Depth Documentation – Rub of the outer air seal (left) is shown to be light and in isolated areas, and knife edge grooving of the inner air seal (right) is shown to be moderate.*

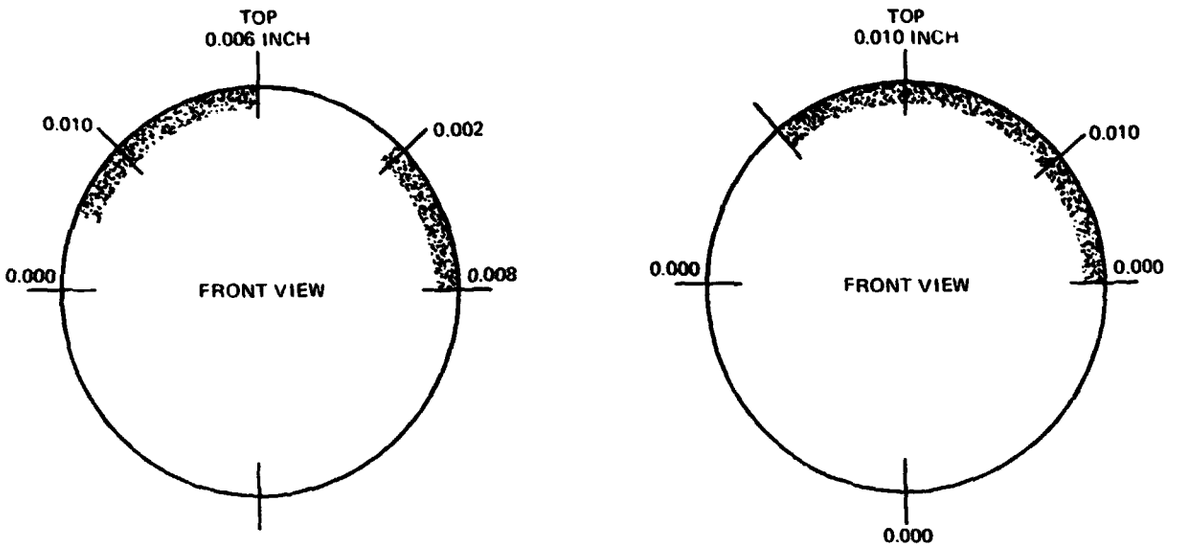


Figure 23 *Eighth-Stage Compressor Seal Circumferential Rub Location and Depth Documentation – Rub of the outer air seal (left) is shown to be light and in isolated areas, and knife edge grooving of the inner air seal (right) is shown to be moderate.*

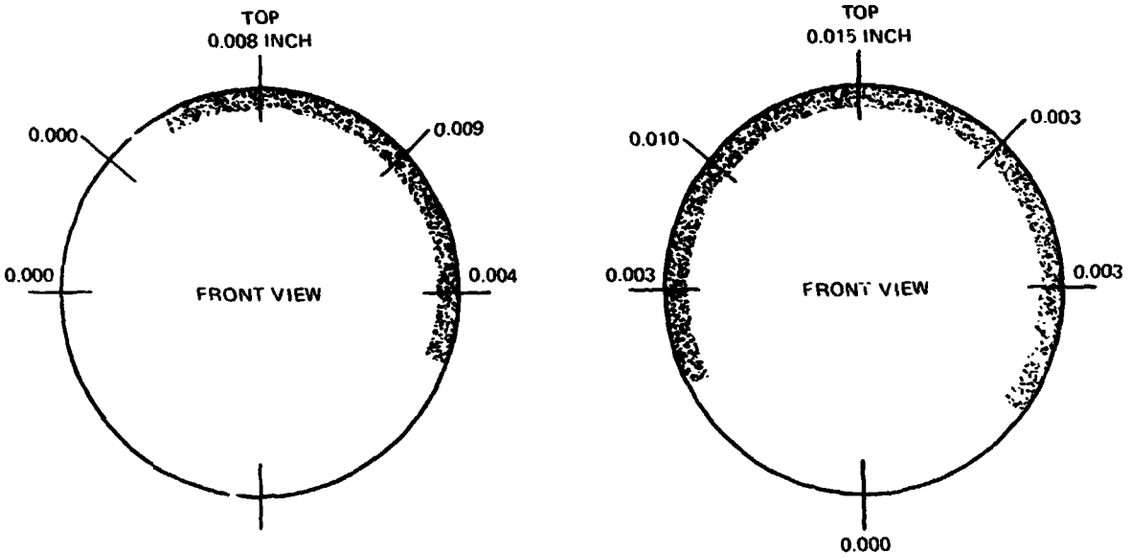


Figure 24 *Ninth-Stage Compressor Seal Circumferential Rub Location and Depth Documentation – Rob of the outer air seal (left) is shown to be light, and knife edge grooving of the inner seal (right) is shown to be light.*

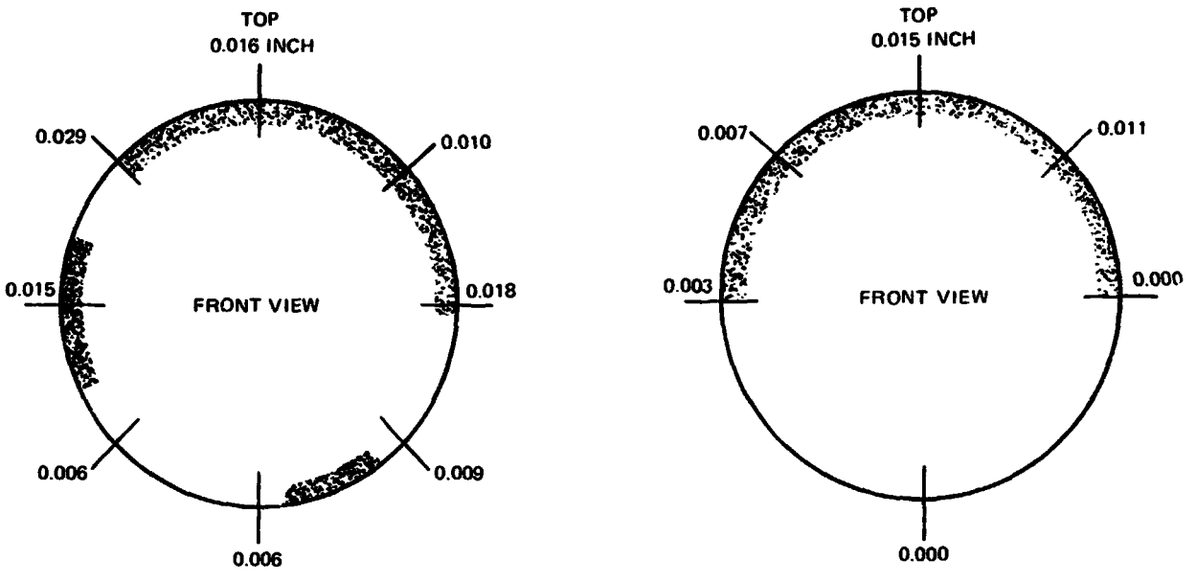


Figure 25 *Tenth-Stage Compressor Seal Circumferential Rub Location and Depth Documentation – Rub of the outer air seal (left) is shown to be moderate, and knife edge grooving of the inner air seal (right) is shown to be moderate.*

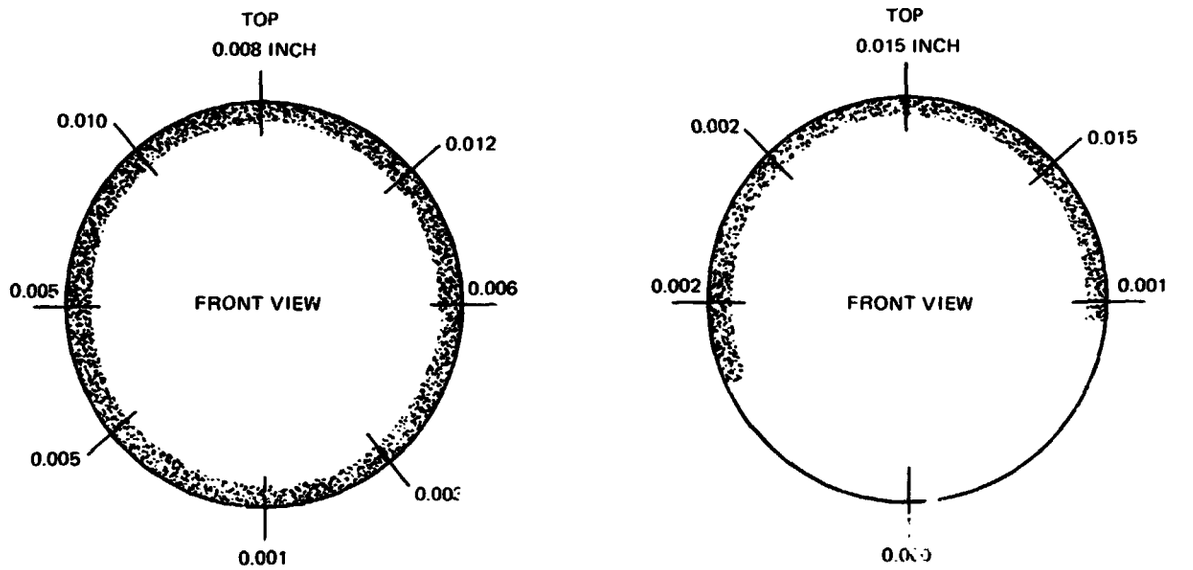


Figure 26 *Eleventh-Stage Compressor Seal Circumferential Rub Location and Depth Documentation – Rub of the outer air seal (left) is shown to be light, and knife edge grooving of the inner air seal (right) is shown to be moderate.*

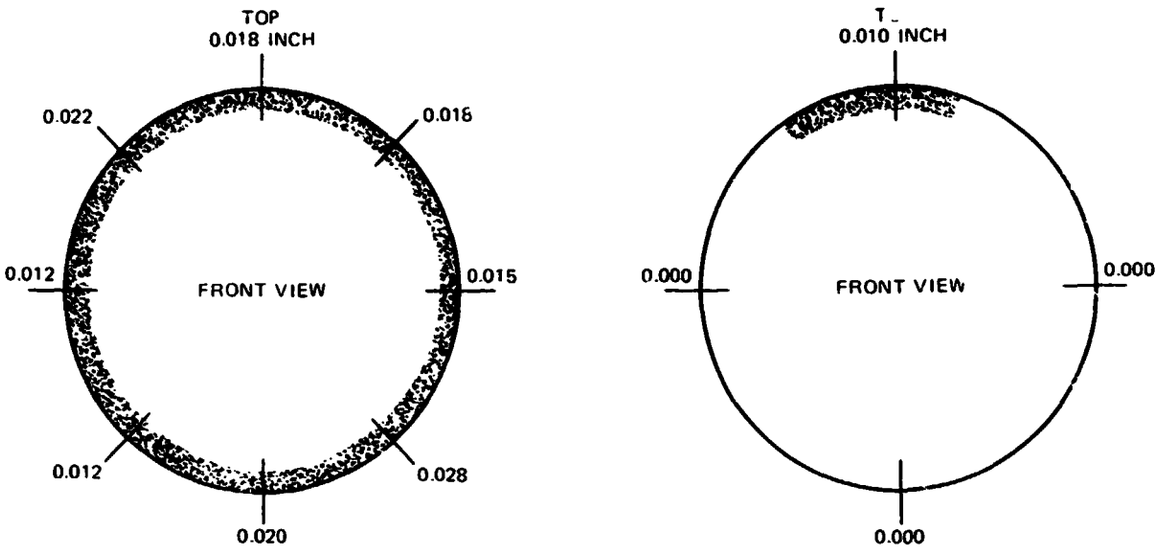


Figure 27 *Twelfth-Stage Compressor Seal Circumferential Rub Location and Depth Documentation – Rub of the outer air seal (left) is shown to be moderate to heavy, and knife edge grooving of the inner air seal (right) is shown to be light.*

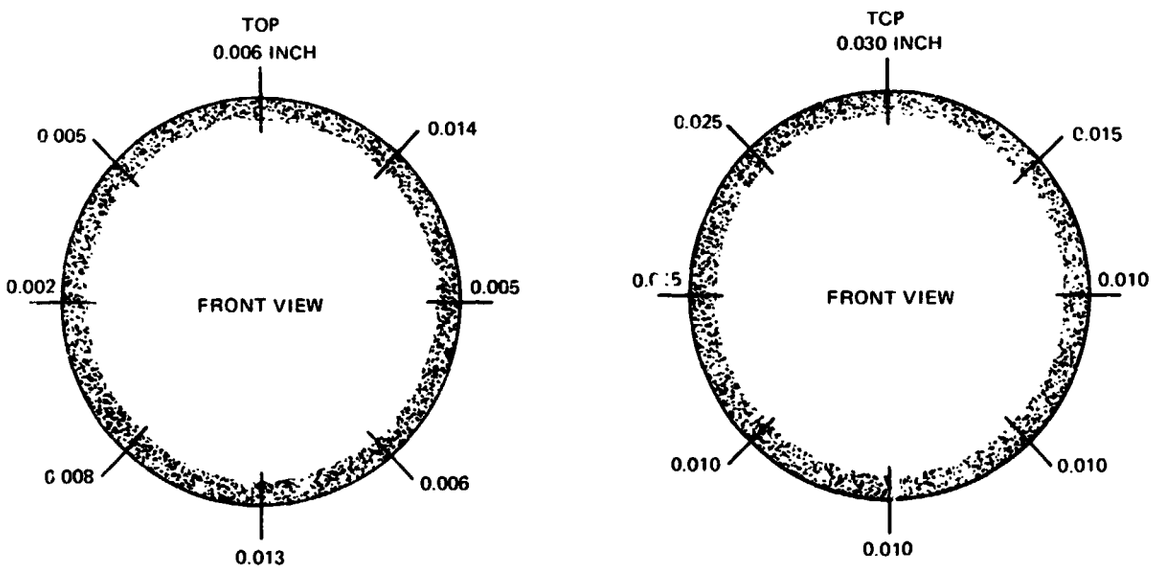


Figure 28 *Thirteenth-Stage Compressor Seal Circumferential Rub Location and Depth Documentation Rub of the outer air seal (left) is shown to be light to moderate, and knife edge grooving of the inner air seal (right) is shown to be light to moderate.*

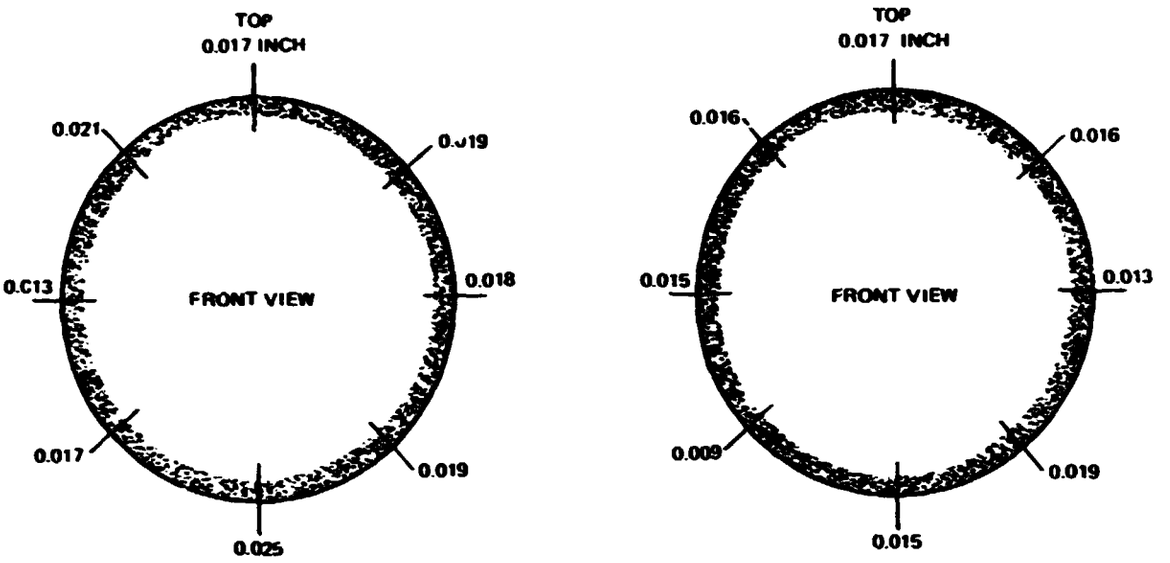


Figure 29 *Fourteenth-Stage Compressor Seal Circumferential Rub Location and Depth Documentation* *Rub of the outer air seal (left) is shown to be heavy, and knife edge of the inner air seal (right) is shown to be light to moderate.*

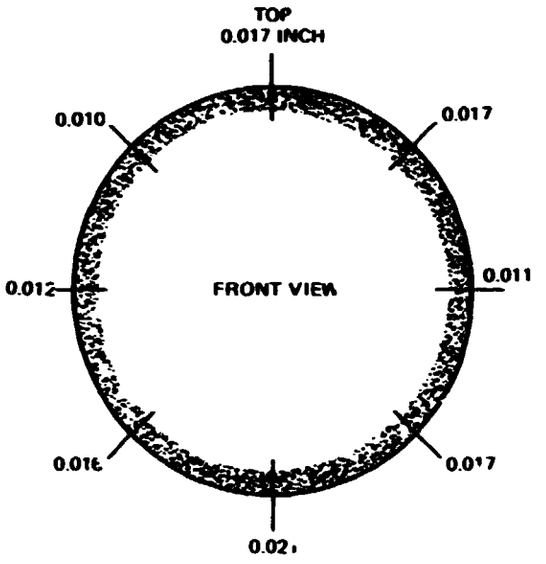


Figure 30 *Fifteenth-Stage Compressor Seal Circumferential Rub Location and Depth Documentation* *Rub of the outer air seal is shown to be heavy.*

Surface Roughness

Airfoil surface roughness ranged from 40 AA on the ninth-stage blades to 15 AA on the 14th- and 15th-stage blades. The average roughness approaches 32 AA which is the average roughness for new engines. The performance impact as a result of surface roughness was insignificant, and no penalty was assigned.

Other Physical Conditions

Typical photographs of the high-pressure compressor blades, stators, and inner and outer air seal hardware are shown in Appendix G. All blade root and case flange sealant was found in generally excellent condition. Flange bolts were tight such that the mating surfaces were well sealed. The airfoils were like new with no FOD or erosion except for one blade on the sixth-stage rotor which had an as-received blended radius on the leading-edge tip. All of the variable stator vane assemblies were found to be in excellent condition, both operationally and from a durability standpoint. The 3.5 bleed system, which provides for high-pressure compressor stability margin during off-design operation, was functionally inspected, and no discrepancies or leakage problems were found.

Summary

A summary tabulation of high-pressure compressor efficiency loss is shown in Table XIV.

5.4 DIFFUSER/COMBUSTOR

Even though the diffuser/combustor module has no direct contribution to TSFC, the combustor hardware can influence the performance of the turbines.

TABLE XIV
SUMMARY OF HIGH-PRESSURE COMPRESSOR EFFICIENCY LOSSES

TEST RESULTS

Module	Δ Eff. (%)	$\frac{\Delta \text{TSFC}}{\Delta \text{Eff.}}$	Δ TSFC (%)
High-Pressure Compressor	-0.2	-0.6	+0.12

ANALYTICAL TEARDOWN RESULTS

Efficiency Loss			Equivalent
Airfoil Roughness	Tip Clearance	Δ Eff. (%)	Δ TSFC (%)
0.0 point	-0.2 point	-0.2	+0.12

During the analytical teardown and inspection, the diffuser/combustor sections were found to be in excellent condition. Hardware in these sections was visually and dimensionally inspected to establish any regions where deterioration or change could account for some of the performance losses established for the turbines. The diffuser section was in excellent condition. Figure 31 shows the condition of the 15th-stage stator and the high-pressure compressor discharge flowpath into the diffuser case. The burners were in excellent condition as shown in Figures 32 and 33. The burner outer liner showed no burn streaks, no cracks, some dimple closure, some carbon on the trailing edge of the carbon cylinders, some carbon film on the swirler bellmouth, some carbon film on the false heads, and some slight erosion on the false head OD corners at the hub location. On the burner inner liner, there were no dimple cracks, some indications of minor streaking, and some minor magnesium zirconate flaking. The overall burner critical fits were all within blueprint tolerances.

The fuel nozzles were in excellent condition, as shown in Figure 34, with only minor indications of coking. During the "as-received" bench calibration of the fuel nozzles, all of the nozzle primary flows and spray patterns were well within limits. During the secondary flow check, some of the nozzles (7 of 20) had flows outside of limits, on the low side as shown in Figure 35, and most of the nozzles (18 of 20) demonstrated light streaking of the spray pattern. All of the nozzle minor flow deviations and spray pattern streaking were corrected and brought within limits by brushing and flushing the parts.

Overall, the diffuser/combustor module mechanical condition was such that no hardware deterioration or change could be measured that should have contributed short-term performance deterioration.

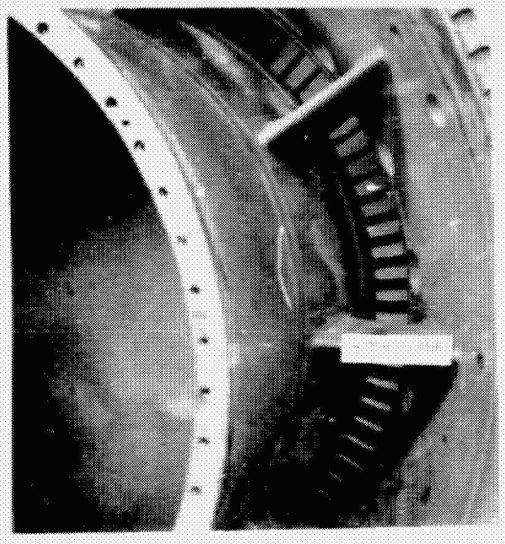
5.5 HIGH-PRESSURE TURBINE

During P-695743 engine testing using expanded instrumentation, high-pressure turbine efficiency was calculated, plotted, and estimated at an engine pressure ratio level corresponding to take-off power. Figure 36 shows the operating line of high-pressure turbine efficiency for all of the calibration points along with the efficiency level at sea level take-off. Compared to high-pressure turbine efficiency for new production engines, the measured short-term deterioration in the high-pressure turbine efficiency is estimated as -0.7 point.

The estimated efficiency was adjusted to reflect the impact of the closed high-pressure compressor variable vanes on the operating characteristics of the high-pressure turbine. This adjustment was developed based on experimental engine experience.

Analytical Teardown

During the analytical teardown and inspection, the high-pressure turbine module was found to be in generally good condition. Measurements of the high-pressure turbine blade tip clearance, blade length, rub depth, rub location, cold flows, vane width, vane tilt, flow passage area, etc., as well as visual observation on the parts condition, were made.



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Figure 31 ***High-Pressure Compressor Diffuser Case*** *– The diffuser flow path from the 15th-stage stator was in excellent condition. (77-444-0254-BG)*

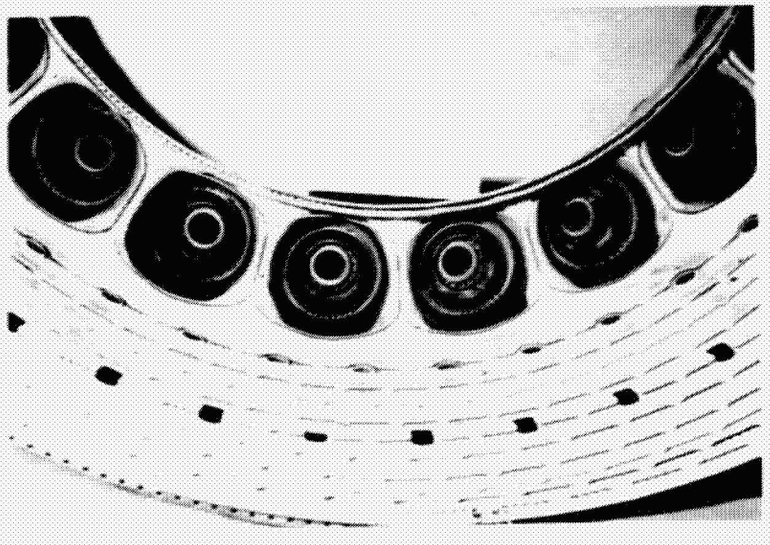


Figure 32 ***Sectional View of Combustor Outer Liner*** *– The combustor outer liner was in excellent condition with only minor carbon film build up. (77-444-0254-R)*

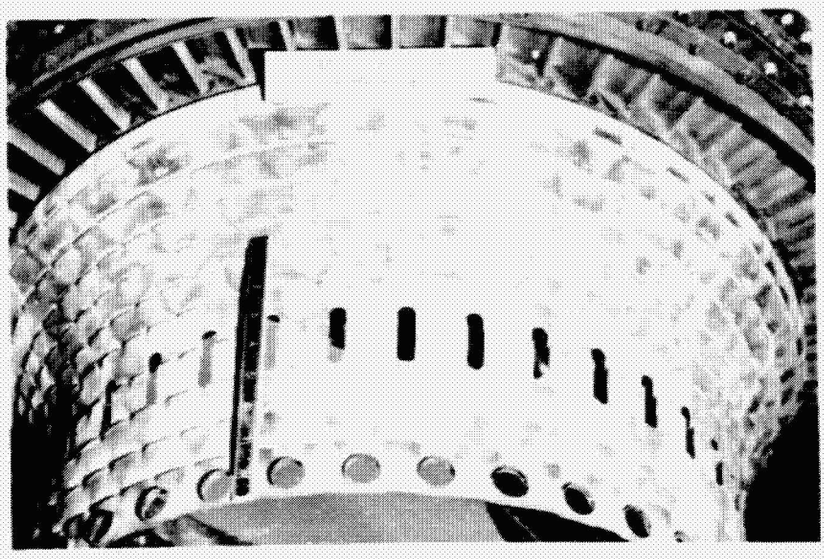


Figure 33 *Sectional View of Combustor Inner Liner – The combustor inner liner was in excellent condition with only minor carbon film build up. (77-444-0254-N)*



Figure 34 *General View of Fuel Nozzles – The nozzles were in excellent condition with only minor indications of coking. (77-444-0254-AZ)*

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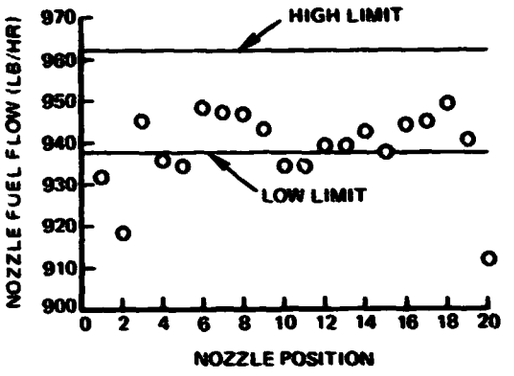


Figure 35 *Fuel Nozzle "As-Received" Calibration -- Seven of twenty nozzles showed low secondary fuel flow.*

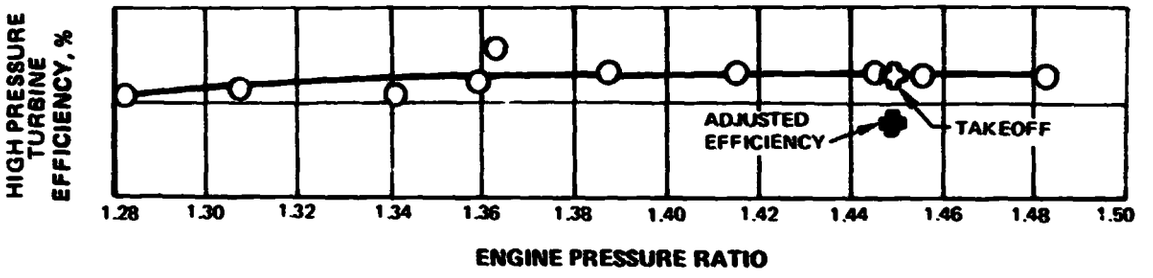


Figure 36 *High-Pressure Turbine Performance – Efficiency data indicated a loss of 0.7 point in efficiency for the high-pressure turbine.*

Outer Air Seal Clearances

The first-stage high-pressure turbine rotor tip clearance at midchord and the first-stage outer air seal rub patterns showed similar wear and rub characteristics as those in engines after production acceptance test as shown in Table XV. Additional study and detailed blade tip measurements by shadowgraph (at 20-X magnification) showed additional wear of 0.014 in. at the blade leading edge and 0.009 in. at the blade trailing edge, with the wear being reduced to zero at the blade midchord. This type and degree of wear has been assessed, using the design system, to cause a performance penalty of 0.1 point in high-pressure turbine efficiency. The second-stage high-pressure turbine outer air seal average radial groove depth was 0.004 in. less than that for the average new production engine as shown in Table XV. Based on this information it was felt that the second-stage blade tip clearance did not contribute to the test engine performance deterioration since the production acceptance test. The circumferential locations of the rubs and rub depths on the outer air seal were documented as shown in Figure 37.

Inner Air Seal Clearances

The inner air seals were in excellent condition and showed negligible wear or rub indications and were typical of these parts in engines after production acceptance test.

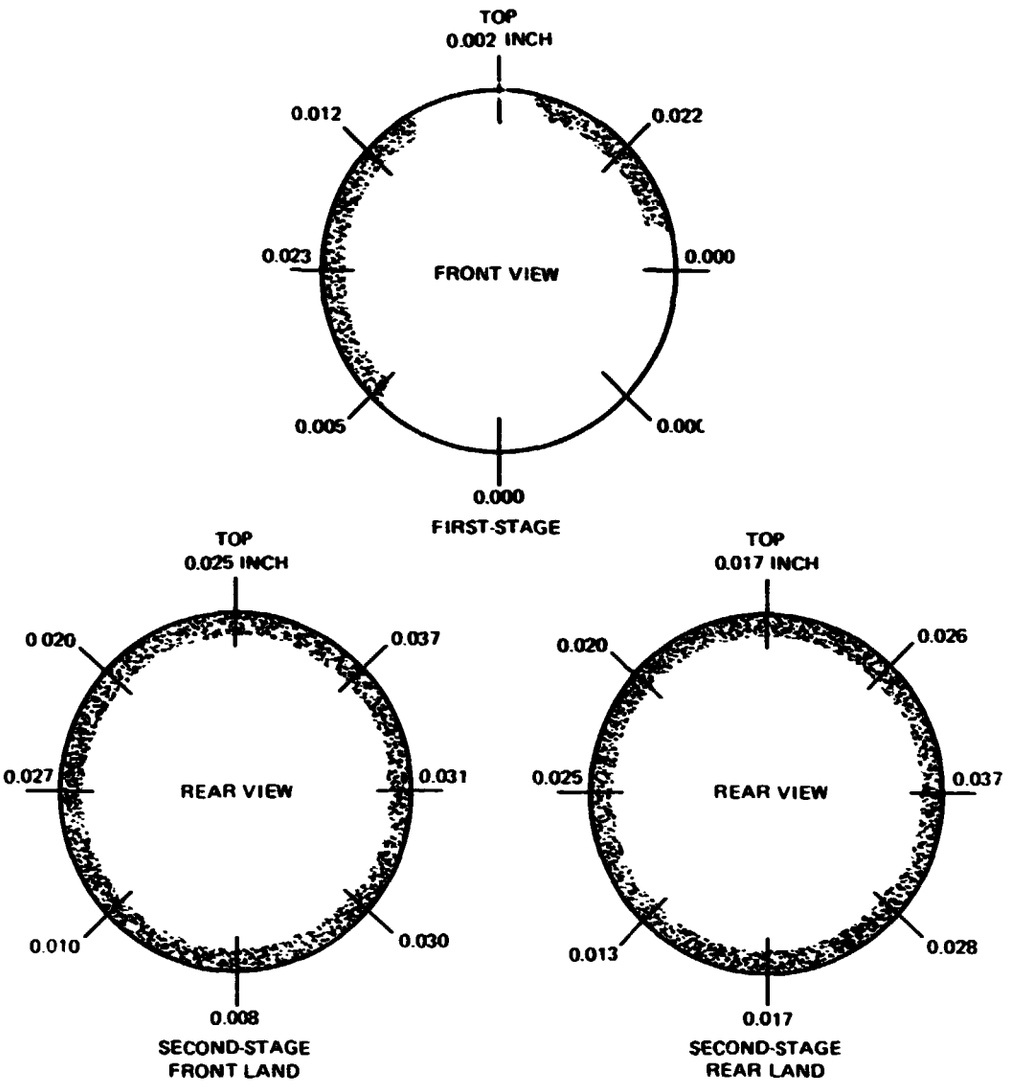


Figure 37 *First- and Second-Stage Turbine Outer Air Seal Circumferential Rub Location and Depth Documentation – Rub locations and depths are shown.*

TABLE XV
HIGH-PRESSURE TURBINE BLADE CLEARANCES

Stage Number	Number of Engines	Clearance (in.) in New Production Green-Run Engines	Clearance (in.) in Test Engine**
1	12	0.078	0.078
2	18	0.027*	0.023*

*Radial groove depth in outer air seal. Tip clearance data not available for second stage of high-pressure turbine for green run engines. Tip clearance of second stage of P-695743 was 0.039 inch.

**P-695743

Vane Leakage

There was no vane bowing and no platform mismatch found on the high-pressure turbine inlet guide vanes, even though some vanes had platform cracks (see Figure 38). During a check for potential leakage, the rear portion of the first-stage vane ID support showed dimensions to be smaller than the blueprint dimensions which was interpreted as a tight fit with no performance loss effects. A spattering of magnesium zirconate deposits from the combustor was found on the first-stage blade suction surfaces (as shown in Figure 39) aft of the leading edge of the blades.

An unexpected short-term engine deterioration mode in the high-pressure turbine was identified during the second-stage vane measurements. A sampling of the vanes were measured for feet width growth, twist, and tilt and, as shown in the Weibull plot, Figure 40, the axial widths of the second-stage vane inner feet were found to exceed blueprint nominal dimensions by an average of 0.012 in. All vanes were found to exceed this blueprint maximum width dimension of 1.138 in. This deterioration mode produces a leakage path between the second-stage vane inner feet and the vane shroud, as shown in Figure 41. The size of the triangular leakage area is dependent on the width between the vane feet.

A plot of the second-stage vane twist check showed the vanes to have twisted open at the ID by an average of 20 minutes (see Figure 42). Approximately 15 percent of the vanes are shown to exceed the acceptable limit of 38 minutes. These changes were assessed in a low time service engine. This average twist of 20 minutes results in 0.006 in. larger root gaging distance which was evident and measured in the second-stage vane flow area check. Figure 43 is the Simpson's Rule measurement of the second-stage vane flow area. The twist measurement results are evident in the ID gaging distance increase of 0.006 in. In the Simpson's Rule check, the area under the curve represents the gas flow path of the vanes. In this case, the measured flow area is 129.0 sq. in. relative to an estimated 128.4 sq. in. when new. A plot of the vane ID tilt measurements (Figure 44) showed an average tilt of 0.011 in. from the blueprint nominal tilt. The plot shows that, on the average, the vanes are approximately one-third through the maximum allowable tilt of 0.035 in. Another plot of the second-stage vane shroud assembly tilt of 0.013 in. shown in Figure 45. These results are consistent, both in general trend and orders of magnitude, with the twist measurements on individual second-stage vanes.

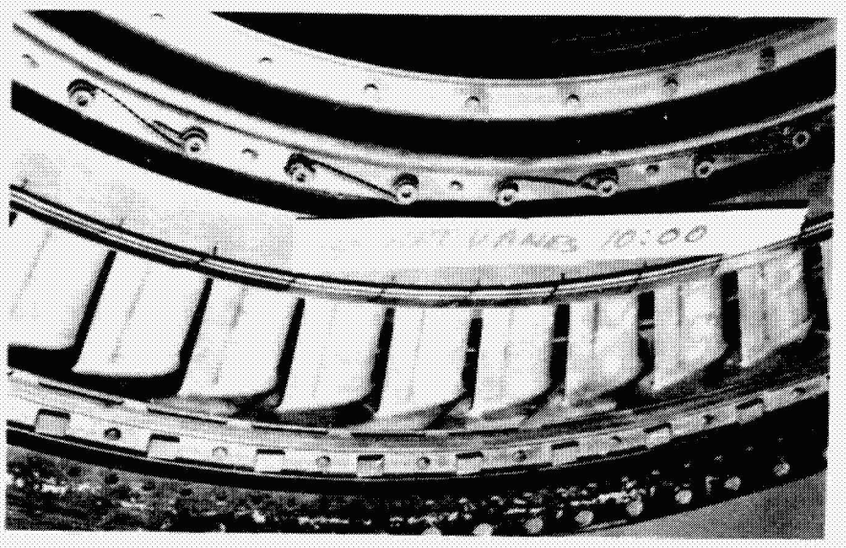


Figure 38 *High-Pressure Turbine Inlet Guide Vanes — No vane bowing nor platform mismatch were found, but some platform cracks were seen. (77-444-0254-P)*

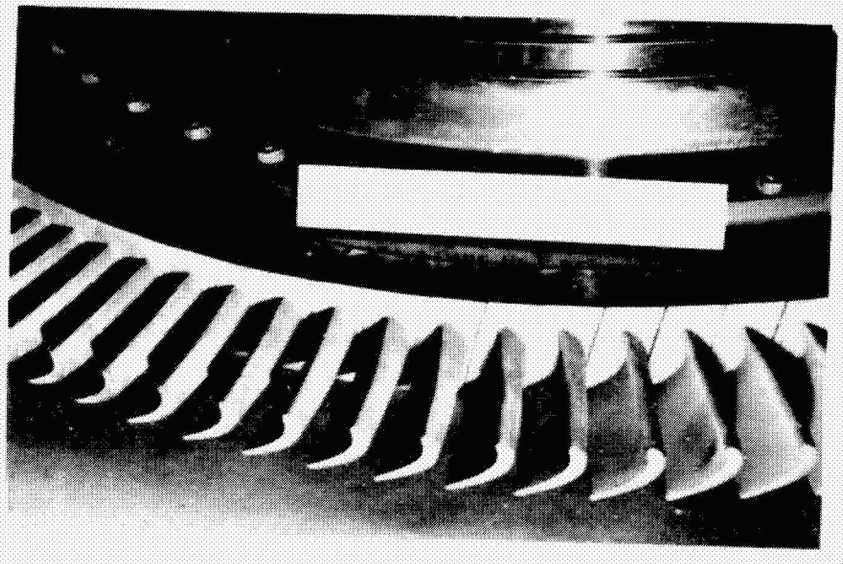


Figure 39 *First-Stage High-Pressure Turbine Blades — The blades were in good condition but spattered with magnesium zirconate deposits from the combustor. (77-444-0254-Q)*

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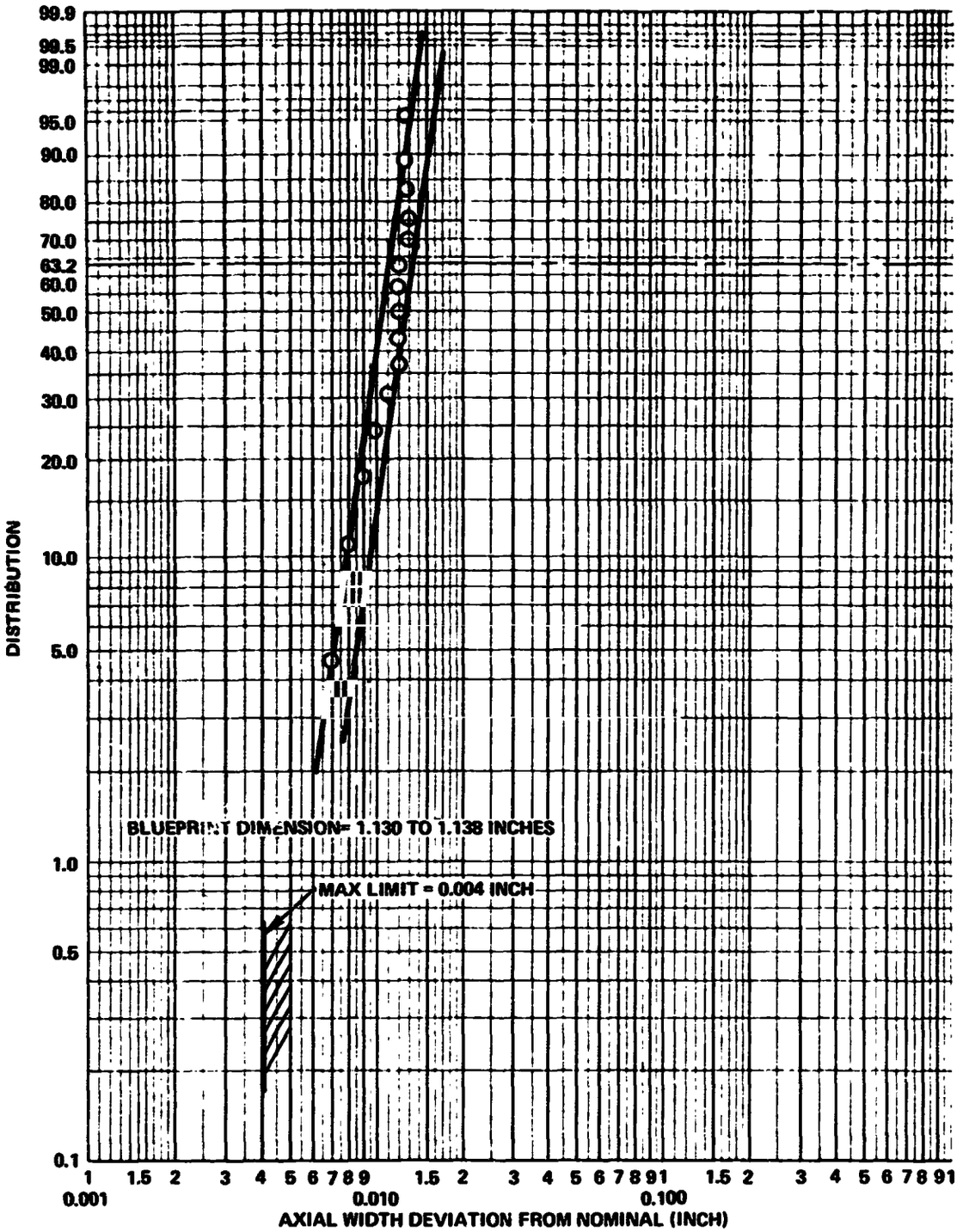


Figure 40 ***Weibull Plot of Second-Stage Turbine Vane Inner Feet Axial Width – Average axial width excee is blueprint dimension by 0.012 inch, and all vanes had foot widths in excess of blueprint maximum width.***

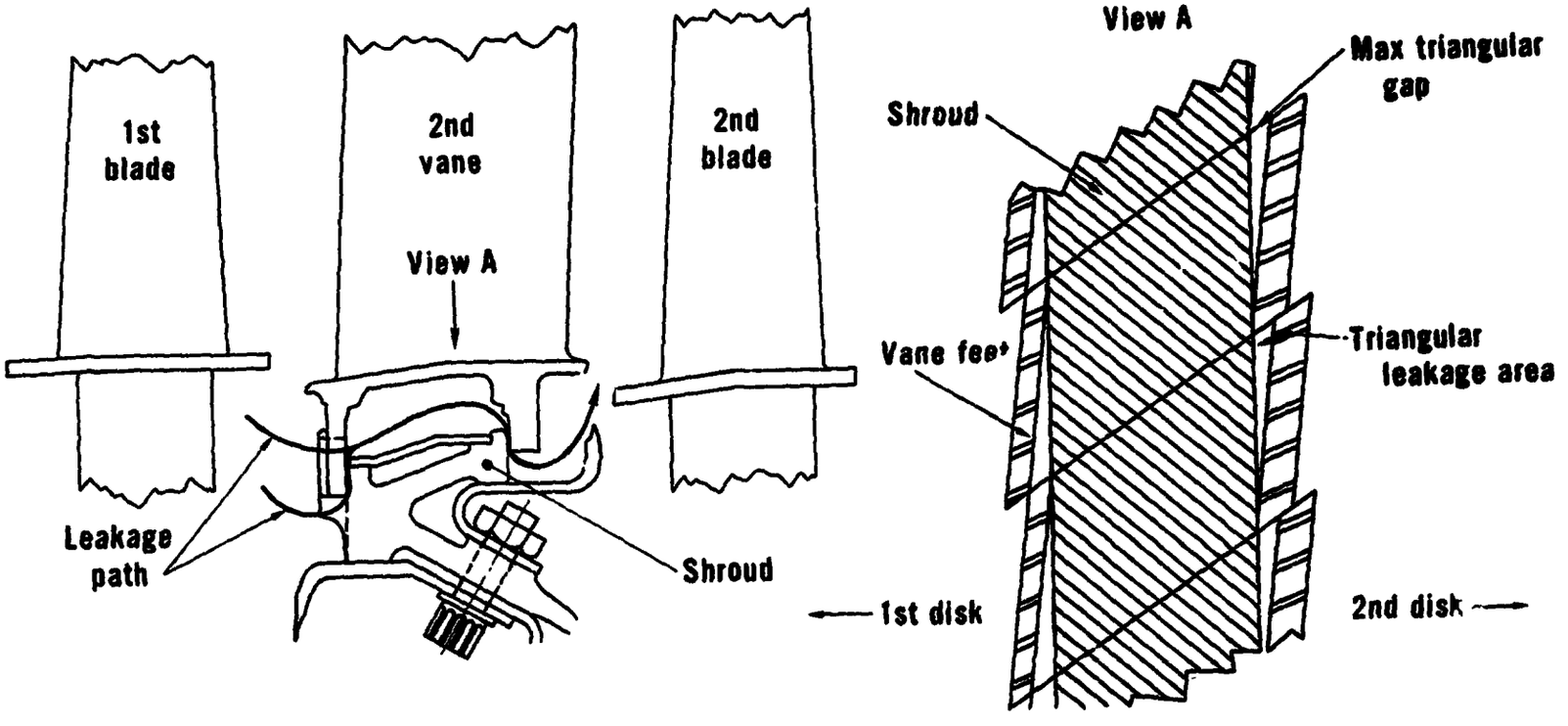


Figure 41 Second-Stage Turbine Vane Leakage – Excessive vane foot width produces a triangular leakage area between the vane feet and the vane shroud.

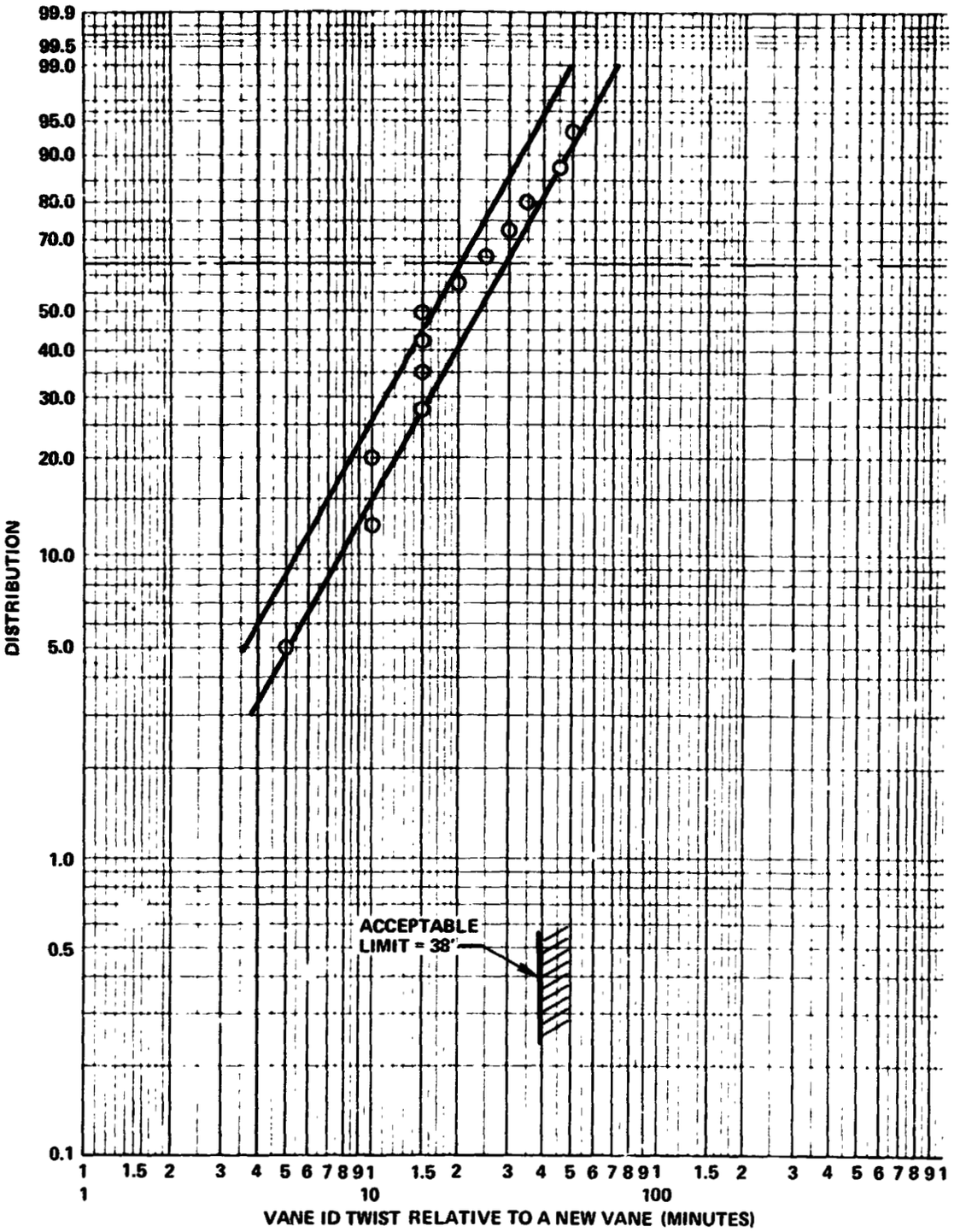


Figure 42 *Weibull Plot of Second-Stage Turbine Vane Twist Measurements – Average ID twist was about 20 minutes which is approximately one-half of the allowable limit, and about 15 percent of the vanes exceeded the allowable limit.*

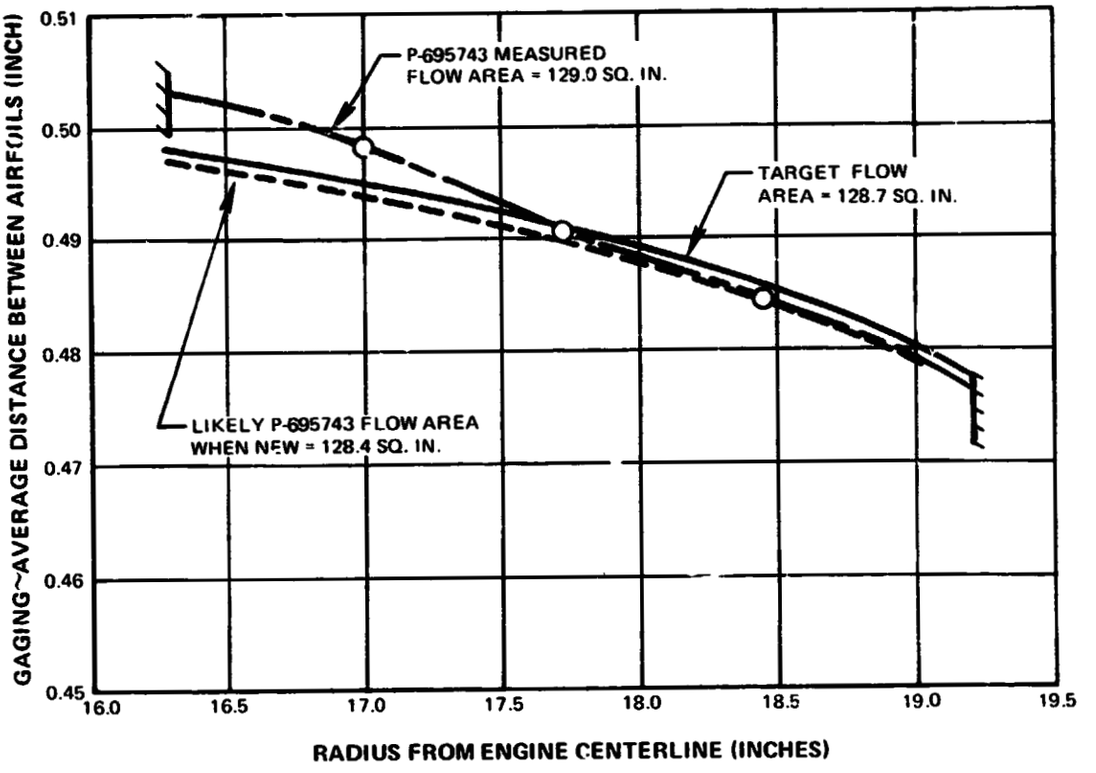


Figure 43 *Second-Stage Turbine Vane Flow Area by Simpson's Rule – Measured vane flow area is shown to be 129.0 sq. in. compared to an estimated 128.4 sq. in. for the new engine and 128.7 sq. in. area specified on the vanes.*

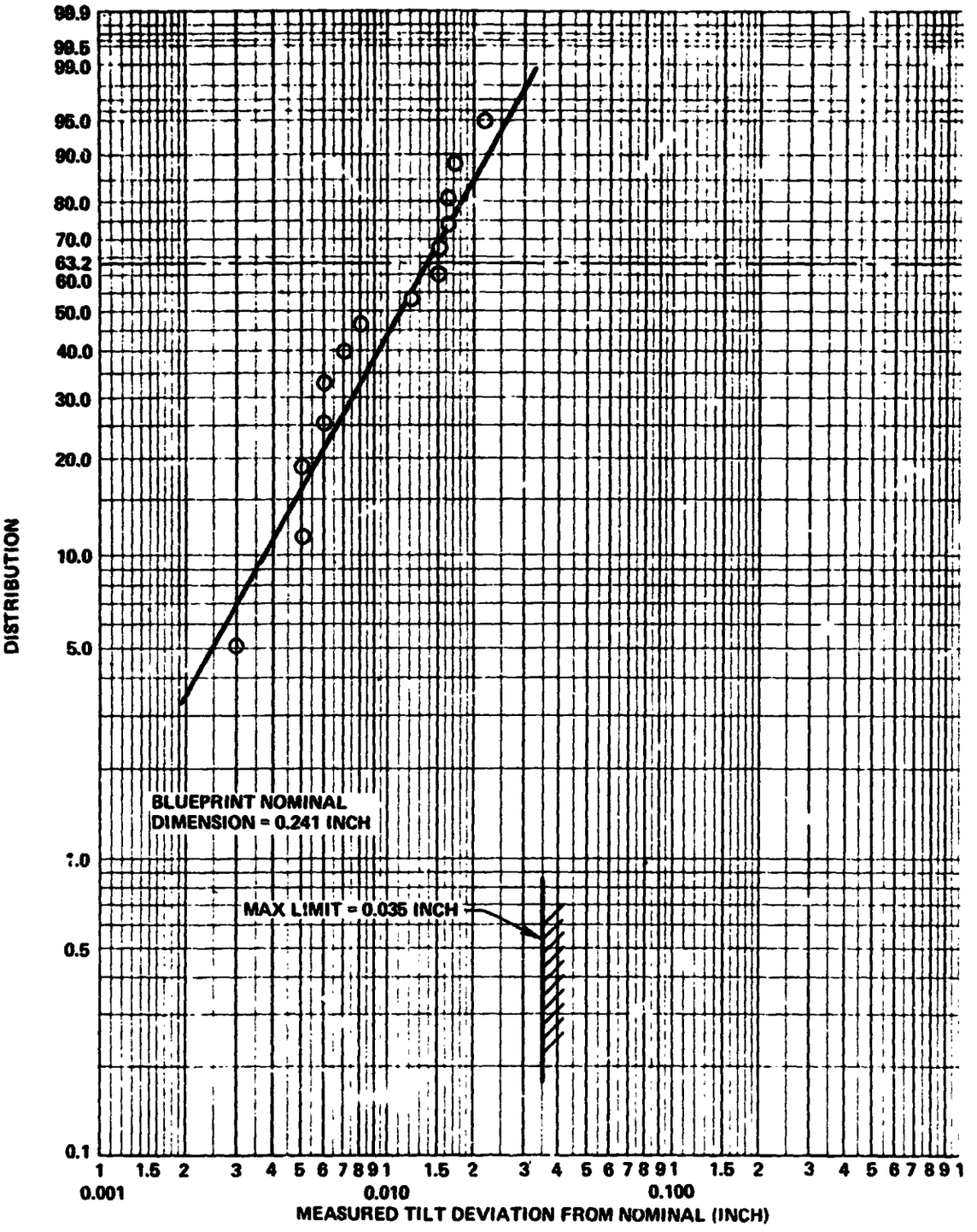


Figure 44 *Weibull Plot of Second-Stage Turbine Vane Tilt Measurements – Average ID tilt was 0.011 inch which is about one-third of the allowable limit.*

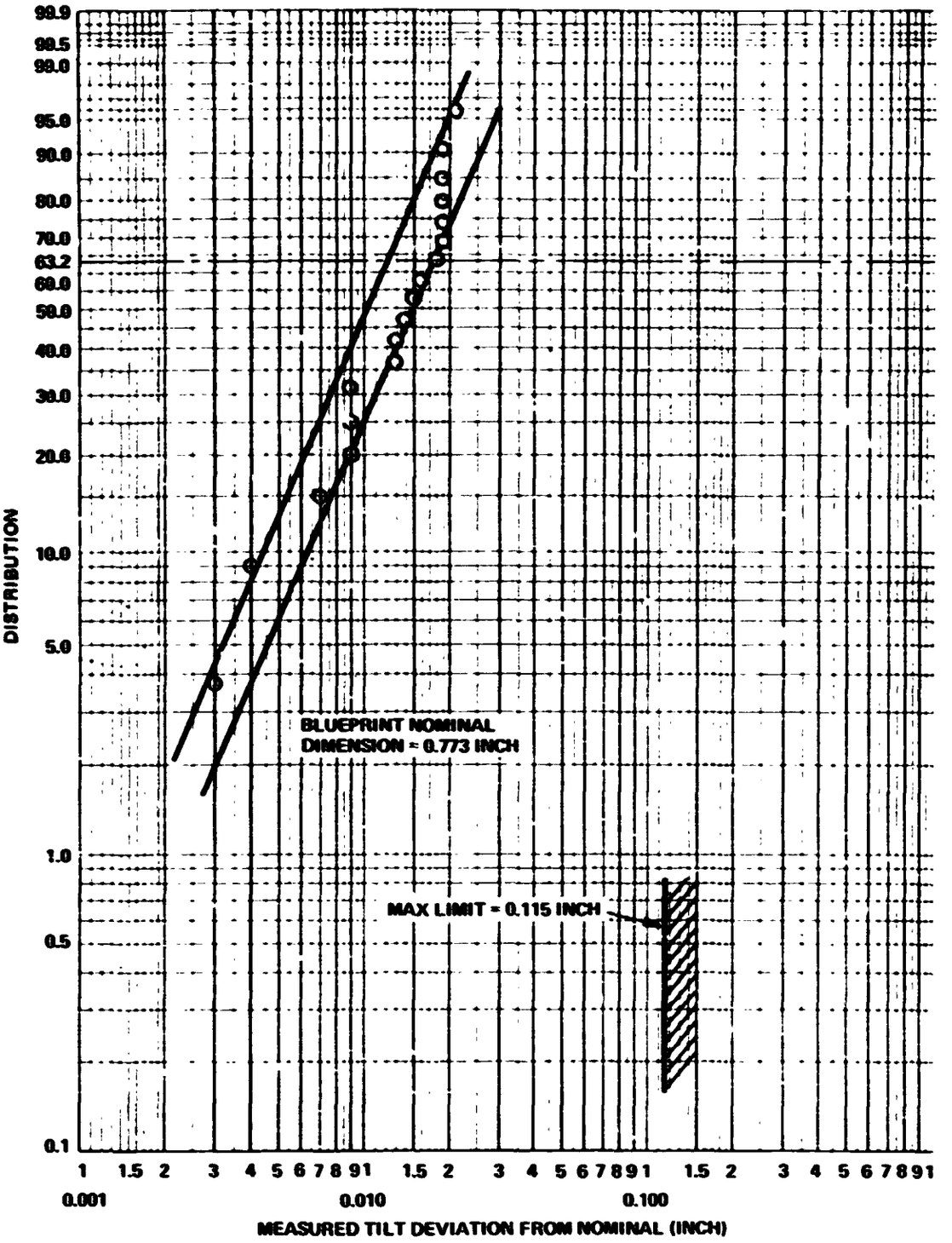


Figure 45 *Weibull Plot of Second-Stage Turbine Vane-and-Shroud Assembly Tilt Measurements – Average tilt, as measured on the assembly, was 0.013 inch which is consistent with measurements on individual vanes.*

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The combined estimated performance penalty due to the second-stage vane width, twist, and tilt deterioration is assessed as -0.6 point in high-pressure turbine efficiency. This performance penalty is due solely to increased second-stage vane ID leakage and is a surprise finding in the short-term deterioration study. This loss estimate is based on data from a previous test program on a high-time engine in which vane foot width growth was first identified and diagnosed as a cause of high-pressure turbine performance loss. The loss in performance due to second-stage vane distortion was, therefore, thought to be a long term performance deterioration mechanism.

Cooling Flows and Areas

Cold flow measurements of the first-stage turbine vanes and blades, second-stage turbine vanes and blades, and the tangential on-board injector (TOBI) duct assembly were all well within calibration limits, as shown in Table XVI, and assessed as having no effects on performance deterioration. Gas path flow area checks by Simpson's Rule were also made of the first- and second-stage turbine vanes and blades. The first-stage turbine vane area by blueprint and classification gage was 82.5 sq. in., but the Simpson's Rule measurement showed 85.1 sq. in. (see Figure 46). The reason for this difference is not apparent, and the variation from blueprint is not believed to be real. Such a change would normally result in a P_{T4}/P_{T2} ratio change of 1½ percent which was not measured during the test. The first-stage turbine rotor blade area check is on target except for the blade tip which appears to be twisted open slightly, starting at midspan (see Figure 47). The second-stage vane specified area was essentially verified by the Simpson's Rule gaging measurements at the OD, but the ID measurements show that the vanes were twisted open, as discussed earlier (Figure 43). The second-stage blade Simpson's Rule measurements show these blades to be on target with no indication of any deterioration, as shown in Figure 48.

TABLE XVI
HIGH-PRESSURE TURBINE AIRFOIL COOLING AIR FLOW AVERAGES

	Measured Average	Location in Tolerance Band (%)	Limits Min	Limits Max
First-Stage Vanes				
Total	1.487*	55	1.315*	1.628*
Showerhead	1.604*	47	1.315*	1.928*
First-Stage Blades	0.00735+	55	0.00683+	0.00777+
Second-Stage Vanes	0.006905+	45	0.0057+	0.0084+
Second-Stage Rotor Assy.	0.273+		At a Pressure Ratio of 1.30 – No Limits	
TOBI Duct	1.873+		1.8587+	1.8873+

*Pressure Ratio, $P_{supply}/P_{ambient}$

+Flow Parameter, $\frac{W\sqrt{T}}{P}$

W = Mass Flow (lb/sec) T = Temperature (°R) P = Pressure (PSIA)

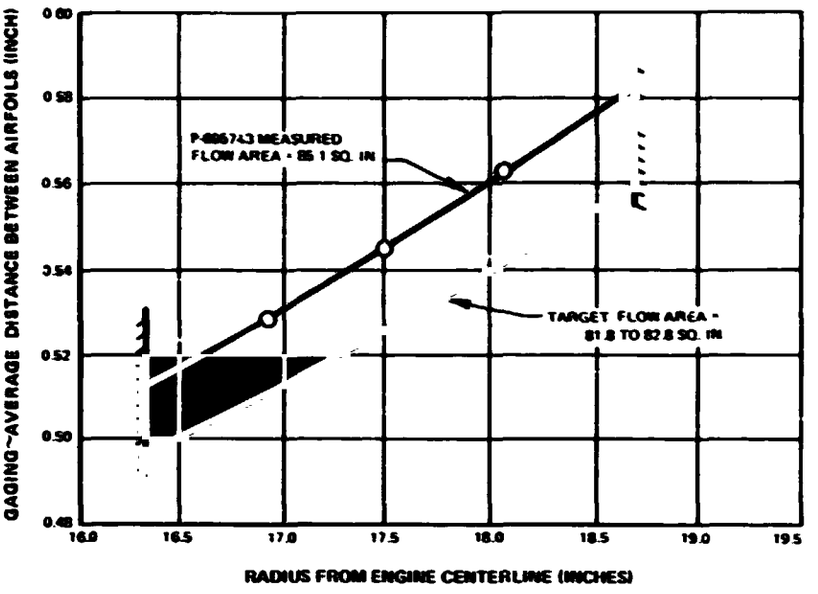


Figure 46 *First-Stage Turbine Vane Flow Area by Simpson's Rule – Measured vane flow area is shown to be 85.1 sq. in. compared to 82.3 sq. in. specified for first-stage vanes; the reason for the discrepancy is not apparent.*

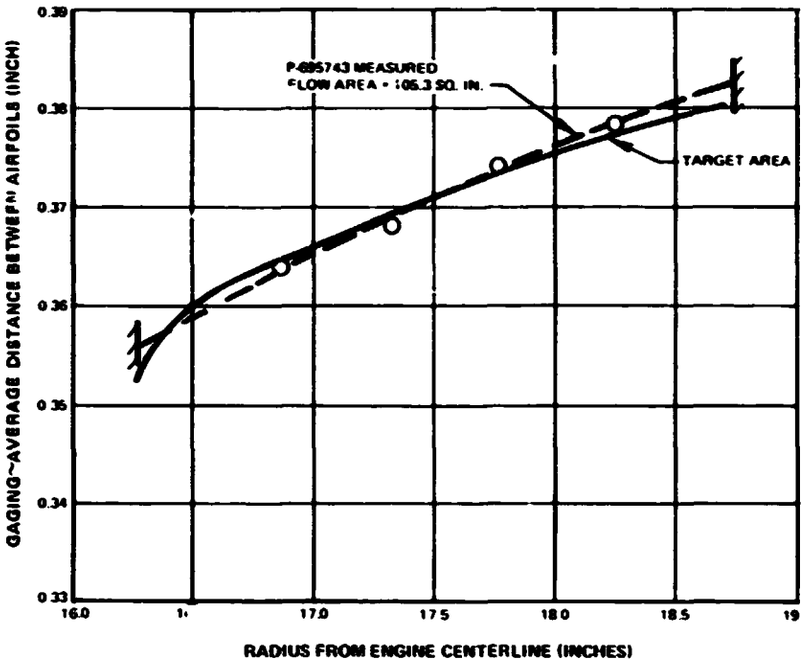


Figure 47 *First-Stage Turbine Blade Flow Area by Simpson's Rule – Measured blade flow area is shown to be 105.3 sq. in. and is essentially on target except for the blade tip which appears to be twisted open slightly.*

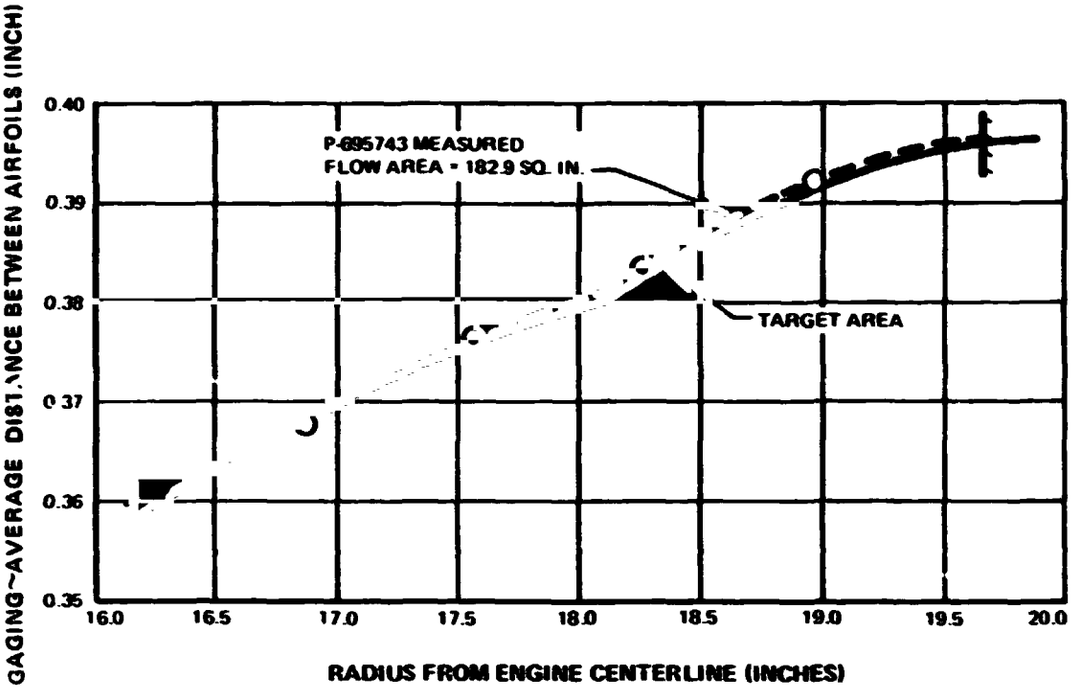


Figure 48 *Second-Stage Turbine Blade Flow Area by Simpson's Rule – Measured blade flow area is shown to be 182.9 sq. in. and is on target.*

The overall deterioration assessment in the high-pressure turbine since the production acceptance test run, as evaluated by the analytical teardown inspection, is -0.7 point in efficiency which is equivalent to +0.47 percent in TSFC.

Summary

A summary tabulation of the high-pressure turbine efficiency loss is shown in Table XVII.

5.6 LOW-PRESSURE TURBINE

During P-695743 engine testing using expanded instrumentation, low-pressure turbine efficiency was calculated, plotted, and estimated at an engine pressure ratio corresponding to takeoff power. Figure 49 shows the operating line of low-pressure turbine efficiency levels. Based on low-pressure turbine efficiency level for an engine after production acceptance test, the measured short-term efficiency deterioration in the low-pressure turbine is estimated, utilizing the design system, as -0.1 point.

The low-pressure turbine efficiency was adjusted to remove the effect of turbine exit case strut losses measured by the turbine exhaust total pressure (P_{T7}) probe system. Rig component efficiencies which form the base line are based on data measured upstream of the struts.

Analytical Teardown

During the analytical teardown and inspection, the low-pressure turbine module was found to be in excellent overall condition. Measurements of the low-pressure turbine tip clearance, inner and outer air seal rub depth and rub location, gas path flow area, etc., as well as visual observations of the parts condition, were made.

TABLE XVII

SUMMARY OF HIGH-PRESSURE TURBINE EFFICIENCY LOSSES

TEST RESULTS

Module	Δ Eff. (%)	Δ TSFC / Δ Eff.	Δ TSFC (%)
High-Pressure Turbine	-0.7	-0.67	+0.47

ANALYTICAL TEARDOWN RESULTS

Efficiency Loss			
First-Stage Blade Tip Wear	Second-Stage Vane ID Leakage	Δ Eff. (%)	Equivalent Δ TSFC (%)
-0.1 point	-0.6 point	-0.7	+0.47

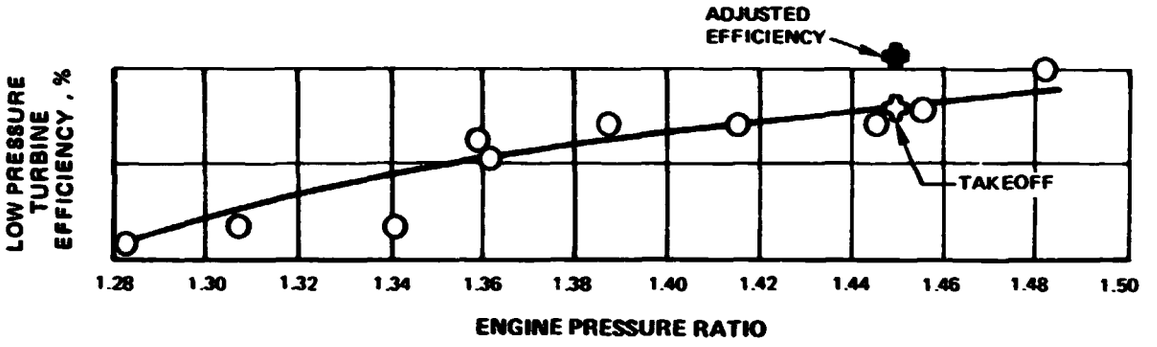


Figure 49 *Low-Pressure Turbine Performance - Efficiency data indicated a loss of 0.1 point in efficiency for the low-pressure turbine.*

Seal Clearances

The blades were in excellent, like-new condition with a minor knife edge "feathering" on the third-stage blades as a result of rubbing. The inner and outer air seal groove depths were very similar to the average engine after production acceptance test, as shown in Table XVIII.

TABLE XVIII
LOW-PRESSURE TURBINE SEAL RADIAL GROOVE DEPTH

Stage Number	Groove Depth (in.) in Average of 16* New Production Green-Run Engines	Groove Depth (in.) in Test Engine**
Outer Air Seal:		
3	0.005	0.007
4	0.005	0.003
5	0.006	0.003
6	0.007	0.005
Avg.	0.006	0.005
Inner Air Seal:		
3 to 4	0.008	0.007
4 to 5	0.012	0.022
5 to 6	0.011	0.008
Avg.	0.011	0.012

*All engines incorporated Mod. II combustors with a cooler OD temperature profile than that for the test engine.

**P-695743

On the basis of these data, no initial deterioration could be attributed to the low-pressure turbine as a result of clearance change. However, the test engine was shipped with a combustor which produces a higher OD temperature profile than that for the engines which form the basis for the green-run average groove depths. A higher OD temperature profile would expand the case and outer air seals of the low-pressure turbine, resulting in less rub during the green run. Assuming that one-half of the total measured grooving and knife edge wear occurred after the green run, the level of low-pressure turbine deterioration would be 0.2 percent as assessed by utilizing the design system. Because of the uncertainties in the above assumption, a range of short-term deterioration of 0 to 0.2 percent in TSFC has been assigned to the low-pressure turbine.

The circumferential locations of the rubs and rub depths on the inner and outer air seals in the low-pressure turbine were documented as shown in Figures 50 through 53.

Flow Areas

The flow area measurement of the third-stage vanes using Simpson's Rule, as shown in Figure 54, correlated well with the design target line, although the area was larger than the target area. The reason for this variation is not apparent, but the performance data seems to corroborate the target area rather than the measured area. Further, no change in area was assessed as having occurred during P-695743 engine operation. Flow area measurements of the fourth-, fifth-, and sixth-stage vane clusters and all low-pressure turbine rotors were not measured since deviations in them would have a second order effect on low-pressure turbine performance. The specified areas on the fourth-, fifth-, and sixth-stage vane clusters were recorded, and the average areas corresponded well with the Bill-of-Materials target areas.

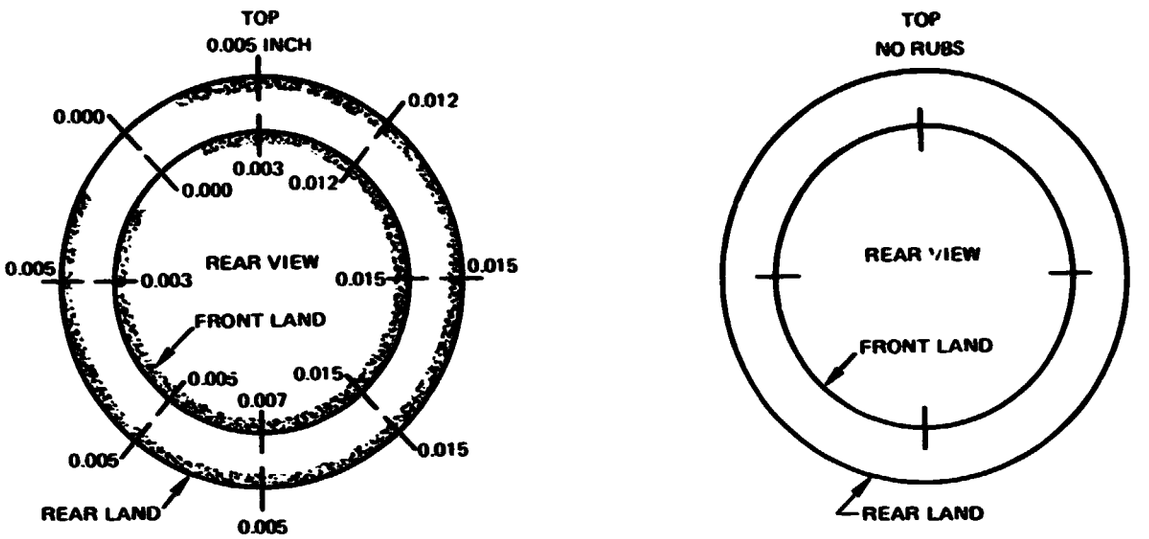


Figure 50 *Third-Stage Seal Centrifugal Rub Location and Depth Documentation – Rub of the outer air seal (left) is shown to be light with no rub of the inner air seal (right).*

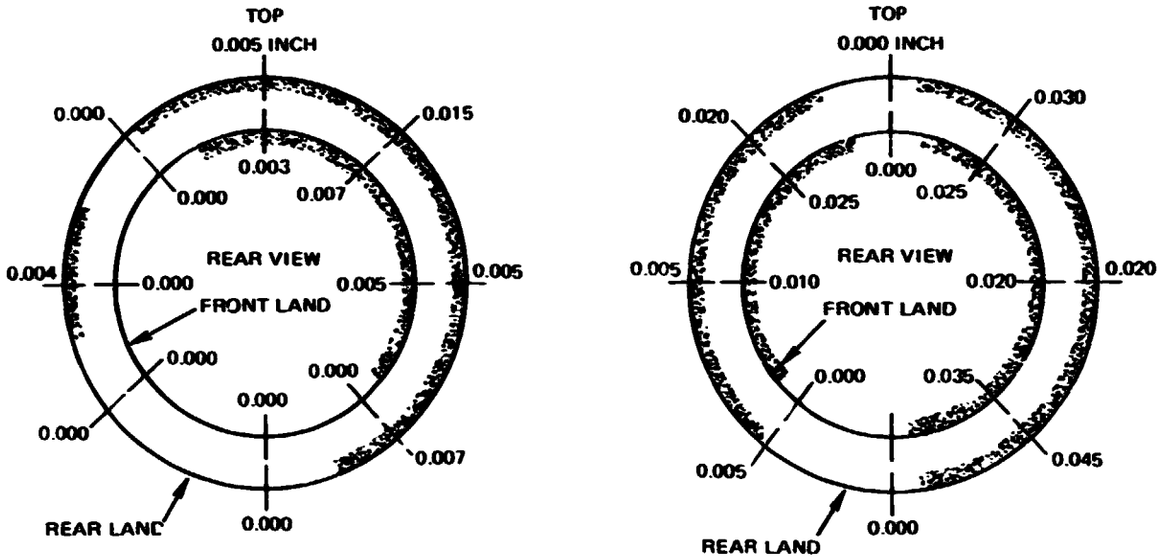


Figure 51 *Fourth-Stage Seal Centrifugal Rub Location and Depth Documentation – Rub of the outer air seal (left) is shown to be light and of the inner air seal is shown to be moderate to heavy.*

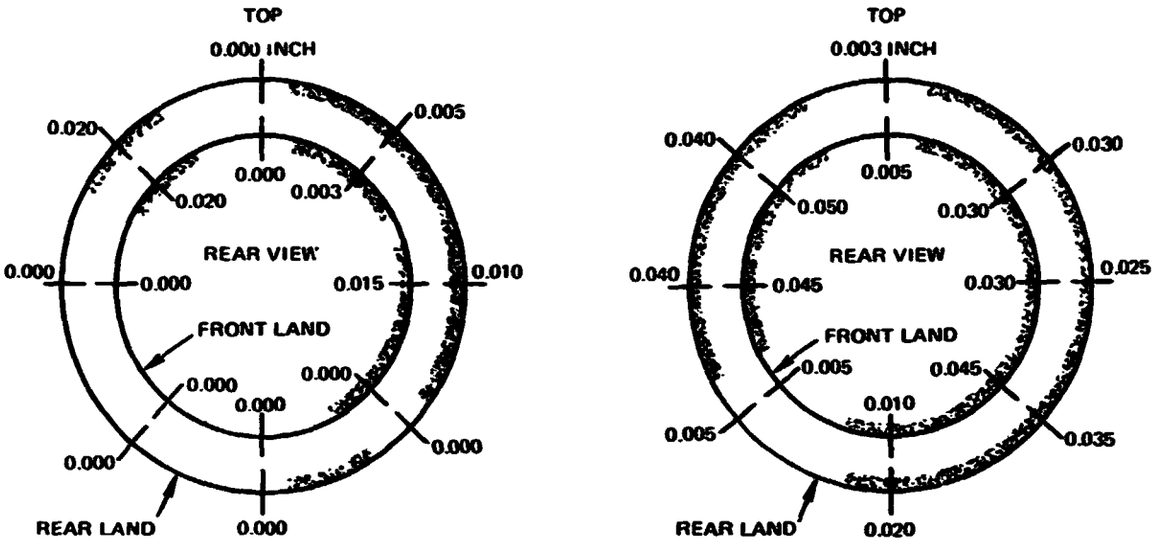


Figure 52 *Fifth-Stage Seal Centrifugal Rub Location and Depth Documentation – Rub of the outer air seal (left) is shown to be light and of the inner air seal is shown to be moderate to heavy.*

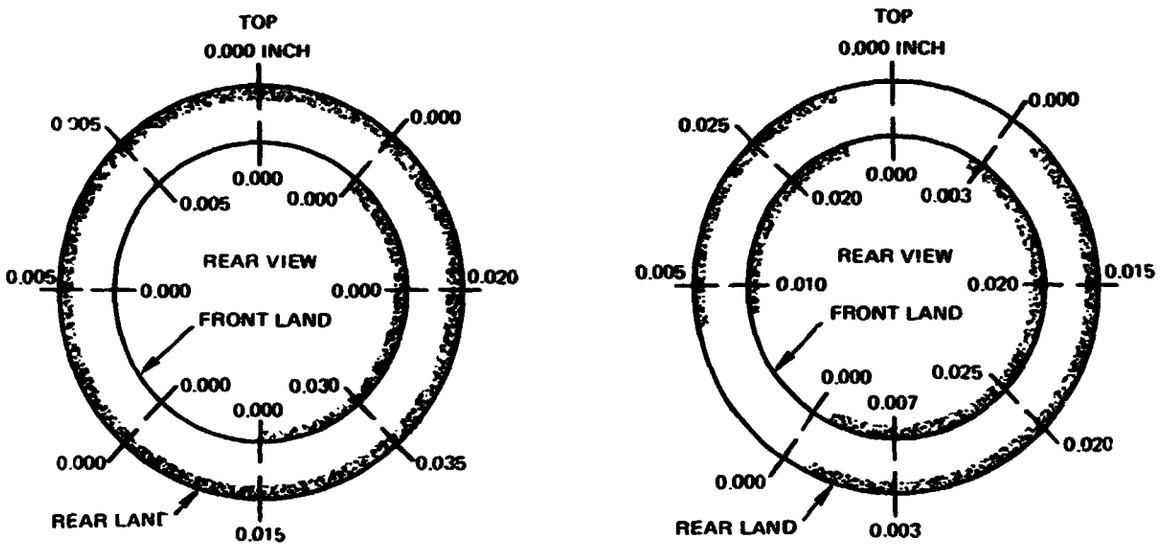


Figure 53 *Sixth-Stage Seal Centrifugal Rub Location and Depth Documentation – Rub of the outer air seal (left) is shown to be moderate to heavy and of the inner seal is shown to be moderate.*

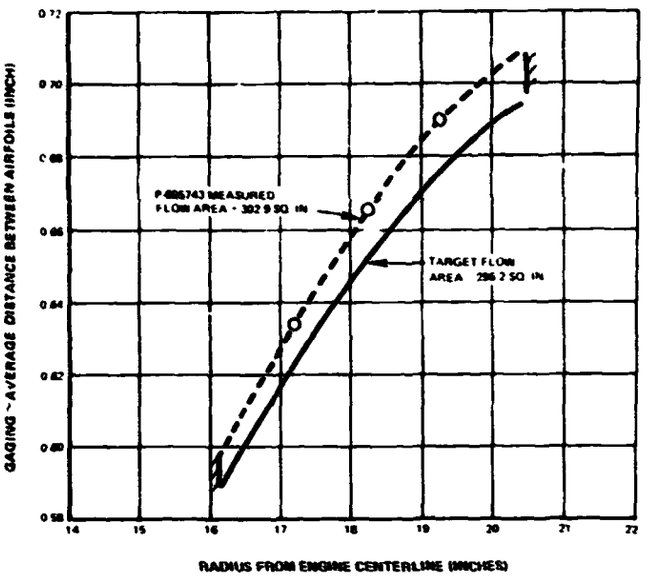


Figure 54 Third-Stage Turbine Vane Flow Area by Simpson's Rule – Measured vane flow area is shown to be 302.9 sq. in. which is larger than the target area specified in the Bill-of-Materials; however, the performance data corroborated the target flow area.

Rotor Sag

The No. 4 bearing support was measured to evaluate a potential sagging condition as a possible cause for the low-pressure turbine rotor droop and resulting performance deterioration.

Turbine exhaust case struts, because of thermal differences in the case, may yield and cause the No. 4 bearing to sag. This sagging condition results in turbine rubbing at the bottom of the engine and increased clearances at the top. The measurements, however, did not show turbine shaft droop to be a short-term engine problem.

Overview of Mechanical Condition

Typical photographs of the low-pressure turbine blades, vanes, and inner and outer air seal hardware condition are shown in Appendix G. The airfoils were like new with no foreign object damage, erosion, or surface roughness problems.

Summary

A summary tabulation of the low-pressure turbine efficiency loss is in Table XIX.

TABLE XIX

SUMMARY OF LOW-PRESSURE TURBINE EFFICIENCY LOSSES

EXPERIMENTAL TEST RESULTS

Module	Δ Eff (-)	Δ TSFC / Δ Eff	Δ TSFC (-)
Low-Pressure Turbine	0.1	1.0	+0.10

ANALYTICAL TEARDOWN RESULTS

Efficiency Loss Tip Clearance	Δ Eff (-)	Equivalent Δ TSFC (-)
0 to 0.2 point	0 to 0.2	0 to +0.2

SECTION 6.0

CONCLUSIONS

The testing and analytical disassembly of P-695743 has significantly improved the understanding of short term engine performance deterioration. The overall TSFC change was measured to be +1.5 percent of which +0.2 percent was due to surface contamination of airfoils, and 0.1 percent was due to the untrimmed stator vane schedule. The distribution of the remaining +1.2 percent performance change in TSFC was attributed to losses at the module level and was assessed by performance testing to be as shown in Table XX.

TABLE XX
PERFORMANCE LOSSES BY MODULES

Module	Δ% TSFC Since New
Fan	+0.15
LPC	+0.35
HPC	+0.12
HPT	+0.47
LPT	+0.10
Total	1.19

The analytical teardown of the test engine permitted further understanding of the causes of deterioration with +0.62 percent TSFC change due to blade tip clearance increase throughout the engine since new, as indicated in Table XXI.

Another major cause of deterioration in this engine was the high-pressure turbine leakage losses due to twisting in the second-stage vanes. This change accounts for +0.40 percent TSFC.

TABLE XXI
MODULE TIP CLEARANCE CHANGE

Module	Average Tip Clearance Change (in.)	ΔEff. (%)	ΔTSFC (%)
Fan	+0.015	-0.15	+0.12
LPC	+0.012	-0.60	+0.21
HPC	+0.002	-0.20	+0.12
HPT	+0.014 (L.E.)		
(1st Stage)	+0.009 (T.E.)	-0.1	+0.07
LPT	+See Sect. 4.6	-0.1	+0.10
	Total		+0.62

The balance of the measured change, +0.20 percent TSFC, was due to airfoil surface roughness changes in the fan and low-pressure compressor. Increased surface roughness and its contribution to short-term performance deterioration was not anticipated, although its role in longer-term deterioration is currently being quantified under other tasks of the NASA JT9D Engine Diagnostics Program.

The clearance changes were anticipated even though the specific time when they occurred would not be directly documented. The overall level of change in clearance was less than expected and may be related to the specific mission profile of this aircraft or flight load levels actually experienced being less than expected over the cumulative flight experience of the engine at time of removal.

The leakage path shown to exist in the second-stage vane was not expected, although other

engine tests at P&WA had identified the problem in a high time engine. Design studies are currently underway to define a simple means to correct this problem.

In overall summary, valuable information has been gained, and the module distribution and mechanisms important in short-term deterioration have been identified. Additional programs of this type would undoubtedly show slight variations in the distribution of losses from clearances, roughness, and thermal distortior of turbine parts. Of these causes, the loss of clearances is judged to be the most critical in short-term performance deterioration for the JT9D and future engines which will rely heavily on tight clearances to obtain needed improvements in energy efficiency.

SECTION 7.0

RECOMMENDATIONS

Additional testing and analytical teardowns of the type reported herein would obviously provide more information from which to draw more precise answers as to the role of each cause and their variability in short-term deterioration. This approach is expensive and is not justified with the state-of-the-art as it exists until other aspects of the deterioration problem have been diagnosed. However, continued monitoring of both engines (P-695743 and P-695745) and inspection of both to the extent possible upon initial removal is both recommended and planned under the NASA JT9D Engine Diagnostics Program.

Of the discrepancies found, both the increased roughness and second-stage vane distortion are sufficiently defined for the moment. Increased roughness is caused by dirt ingestion and no direct method for alleviation of this problem currently exists other than periodic water washing of the engine. The distortion of the second-stage vane is amenable to either direct change out with a stiffer vane assembly (JT9D-7J configuration) or to redesign for increased stiffness.

Continuation of the NASA JT9D Engine Diagnostics Program including both static and dynamic modeling studies of the effect of flight loads on engine clearances is planned. More precise definition of the effect of flight loads and in particular the effect of aerodynamic loads on engine clearances is recommended.

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APPENDIX A

FACILITIES AND PROCEDURES

APPENDIX A
FACILITIES AND PROCEDURES

PLUG-IN-CONSOLE SYSTEM

The Plug-In-Console (PIC) system is a portable unit developed by Pratt & Whitney Aircraft to permit acquisition of engine performance data with the engine on the ground but still mounted on the aircraft wing.

The system is designed to record over 30 parameters, including all of the standard flight deck engine parameters plus additional engine parameters for which special certified probes are permanently installed in the engine. The specific selection of parameters is flexible, but the current list includes the following:

Static Pressure
- Ambient
- Low-Pressure Compressor Discharge
- High-Pressure Compressor Discharge
- High-Pressure Turbine Inlet

Total Pressure
- Low-Pressure Compressor Discharge
- Low-Pressure Turbine Discharge

Total Temperature
- Ambient
- Low-Pressure Compressor Discharge
- Combustor Inlet
- Low-Pressure Turbine Discharge (6 Probes)
- High-Pressure Turbine Discharge (6 Probes)

Other
- Low-Pressure Spool Rotor Speed
- High-Pressure Spool Rotor Speed
- Fuel Flow
- Variable Vane Bellcrank Angle

In addition to the instrumentation installed in the engine, the system consists of three portable units: a power module, a signal conditioning module, and a recording module. The three units are shown in Figure A-1. All three modules are mounted in special carrying cases that protect the units during transport and permit their use by removal of access covers from each case. A typical arrangement of the units during data acquisition is shown in Figure A-2. The signal conditioner module is placed on the ground close to the engine being tested while the other two modules are used in the aircraft. The entire system is powered by the aircraft electrical system and requires less than 500 watts.

The output from the system is in the form of a printed tape indicating temperatures in degrees Fahrenheit, rotor speeds in rpm, and other parameters in millivolts that are converted separately to engineering units.

PRODUCTION TEST STAND

Test Facility

The test facility used to document the level of overall engine performance deterioration was Test Stand No. 4 at Pratt & Whitney Aircraft's Middletown, Connecticut JT9D Production Test Facility. This test stand was the same as that used during the production acceptance test of the engine. The test stand was specifically designed for testing of high bypass ratio gas turbine engines with airflow rates of up to 3000 pounds/second. Figure A-3 is a schematic view of the test facility.

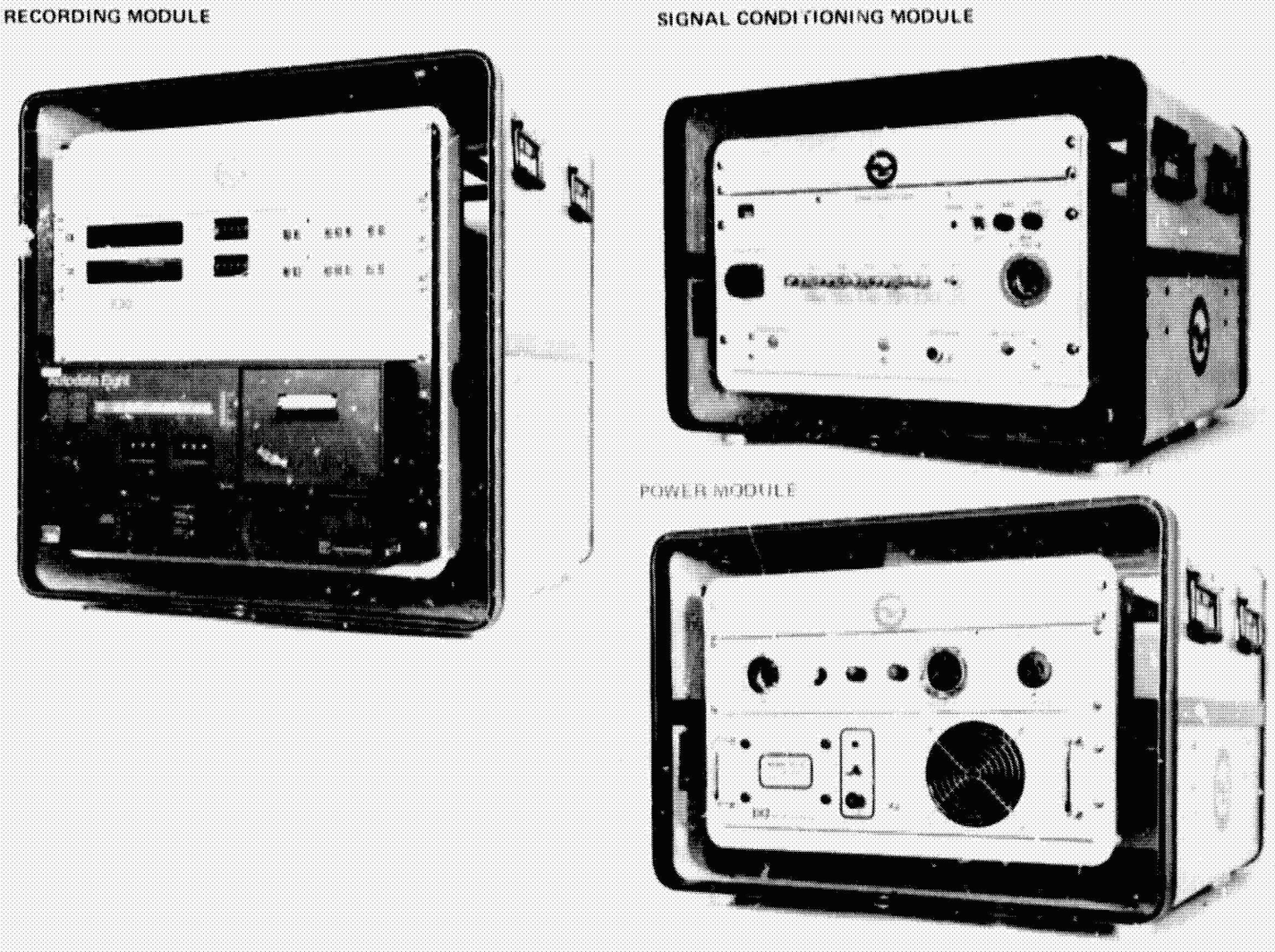


Figure A-1 *Plug-In-Console Modules — These modules working in conjunction with special instrumentation installed in the engine, permit performance documentation of the engine with the engine on the aircraft wing.*

(SS-25383/4/5)

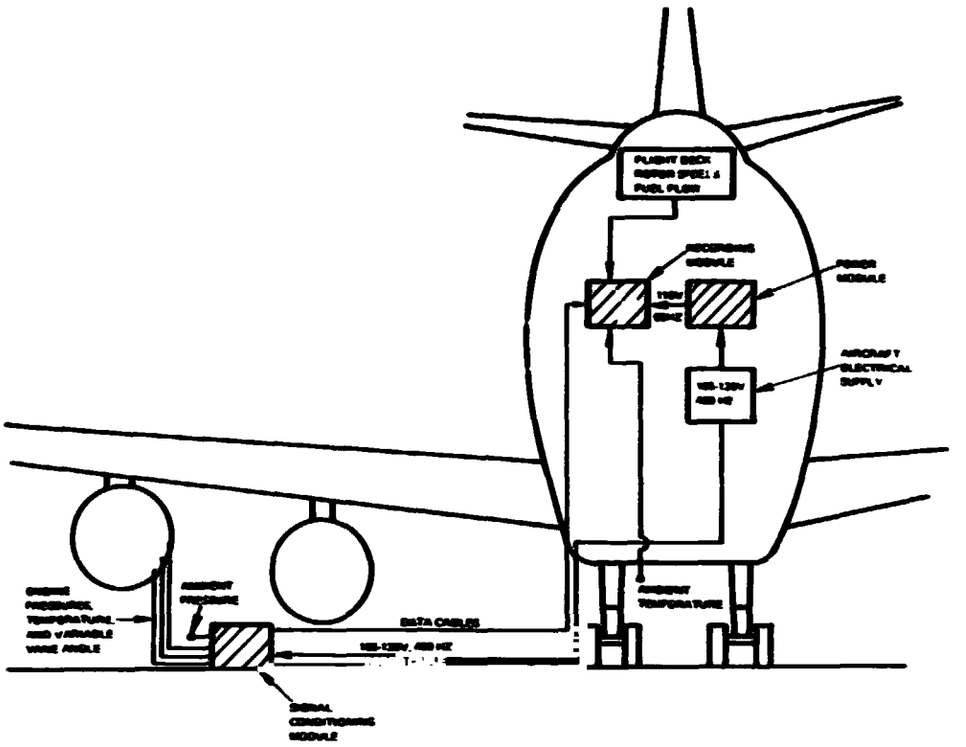


Figure A-2 ***Typical Arrangement of Plug-In Console System During Data Acquisition – The system is easily installed and is powered by the aircraft electrical system.*** *(76-6348)*

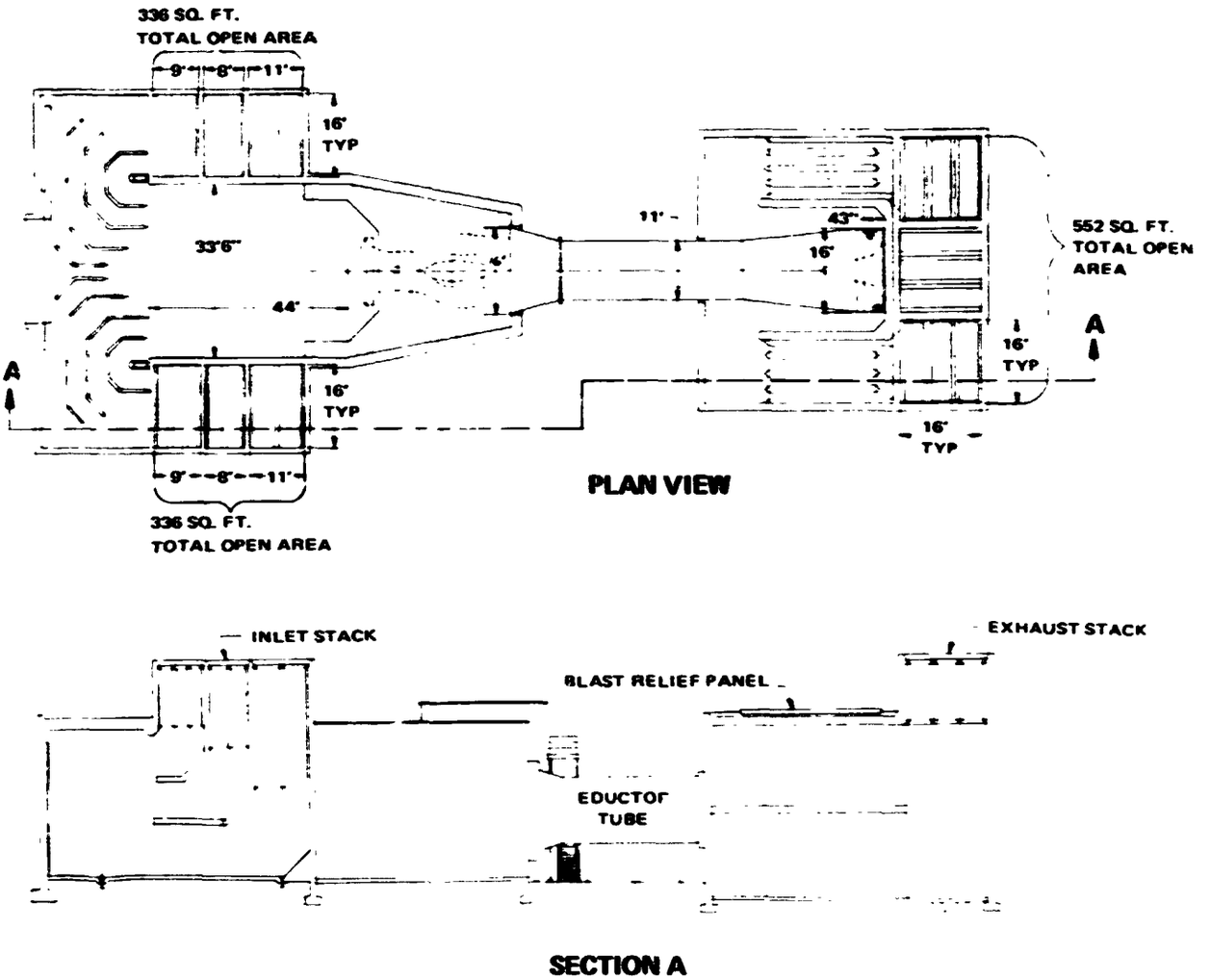


Figure A-3 *Production Test Stand - The production test stands are designed to provide fully automated testing and data acquisition of high bypass ratio turbofan engines.*

The test stand is equipped with a fully Automated Production Test Data Acquisition and Control (APTDAC) System. This system programs the engine test, including the performance of such operations as belting in, ignition, bleed valve checks, trimming, and limit checks. It provides a continuous display of performance parameters for the test operator, including corrected thrust, rotor speeds, and specific fuel consumption. In addition, it warns the operator of any unacceptable operating parameters. The system records, computes, and plots corrected test data, and also prints out the corrected data on the engine acceptance documentation. Figure A-4 is a sample of a log sheet from the production test stand.

Engine mounting is facilitated by an overhead monorail system, as shown in Figure A-5. The system provides automatic positioning of the engine, minimizing the time required for preparing the engine for testing.

Noise suppression was of particular concern in the design of the test stand, with the result that both the inlet and exhaust systems consist of labyrinth baffling constructed of thick reinforced concrete and covered with perforated sound-absorbing panels. These features are illustrated in Figures A-6 and A-7.

The test stand is provided with all required utility services. These include electric power at 110 and 440 volts at 60 Hz; electric power at 28 volts DC and 400 Hz; steam at 25 psig; shop air at 100 psig; starter air at 350 psig; water; and fuel.

The controls and instrumentation required to operate and monitor the engine are located in an adjacent control room, shown in Figure A-8. Continual visual observation of the engine is provided by a window in the test stand wall.

Instrumentation and Data Acquisition System

In Test Stand No. 4, the engine was tested with the required probes and other instrumentation to measure the performance parameters that were monitored on the initial production acceptance test of the engine serial number P-695743. Table A-I lists the parameters that were measured, and Figure A-9 shows schematically the location of the engine probes.

The test stand incorporates an Automatic Production Test Data Acquisition and Control (APTDAC) System which was designed, procured, and programmed by the Government Products Division of the Pratt & Whitney Aircraft Group. The system replaces all visual instrument readout devices with computerized display and control modules. Measurements acquired by the system are converted to engineering units, the converted data are used to calculate the required performance parameters, and the results are checked to determine out-of-limits conditions. The system provides for manual control of the engine by the operator or automatic control and operation of the engine by the computer portion of the system.

The basic computer is a Control Data Corporation (CDC) Model 1704, 16-bit digital computer with a 1.1 microsecond cycle time. The computer also employs a CDC Model 853 disk storage drive for additional storage capacity. The test stand has peripheral devices (line printer, cathode ray tube (CRT) display) for interfacing with the system. The computer also has a teletypewriter, card and paper tape readers, and magnetic tape transports for programmer communications with the computer, rapid storage of bulk data, and as a back up for operating system programs.

LOG OF ENGINE TEST

ENGINE # PA95743 JT9D-7ASP CELL # S DATE 10/28/77 TIME 1145

ENGINE START DATA

WF AT LIGHT 651. MAX WF 1892. MAX EGTMA 867. TIME TO IDLE 45.0 SEC

DATE.....	102877	102877	102877	102877
TIME.....	0121	0126	0131	0136
POINT NO..	174	175	176	177
TEST PART.	ACPCAL	ACPCAL	ACPCAL	ACPCAL

T.I.S. CALCULATIONS

FN/ST2....	36838.	47125.	43552.	31712.
TSFC/KCRM.	.336	.354	.346	.329
WF/KCRMST2	12391.	16690.	15089.	10440.
N1/ROT2...	3025.	3334.	3231.	2851.
N2/ROT2...	7085.	7341.	7235.	6979.
TT6MA/0.91	1319.	1476.	1421.	1231.
PT7/PT2...	1.312	1.457	1.404	1.250
TURB C-AIR	.2948	.2898	.2913	.2962
PT3C/PT2..	2.0640	2.3261	2.2425	1.9215
PS4/PT3C..	8.184	8.879	8.658	7.823
DP3C/PT3C.	.1882	.2272	.2138	.1689
WAEROT/ST2	211.45	245.37	234.54	194.01
WAEROT/ST3	114.37	120.16	118.26	111.75
TT7/OT2T7E	907.27	1007.2	970.62	867.86
TT4/OT2T4F	1279.	1352.	1327.	1239.
WATROT/ST2	1397.8	1567.5	1519.0	1302.5
PS3C/PT2..	1.6796	1.7976	1.7629	1.6971
PS4/PT7...	12.873	14.172	13.825	12.022
PS5I/PT7..	-.146	-.132	-.111	-.187
TT3/0.985.	642.	665.	656.	627.

OBSERVED DATA

FN OBS....	34093.	43628.	40314.	29327.
DFN/ST2CEL	2587.	3245.	3016.	2258.
N1 OBS CTR	3043.9	3348.6	3248.6	2868.6
N2 OBS CTR	7114.7	7322.1	7253.4	6981.5
WF OBS....	12519.	16677.	15131.	10599.
BETA-ANGLE	-1.98	1.74	.61	-3.50
VIB INT...	.72	1.05	.98	.77
VIB DIF...	.73	.81	.74	.63
VIB TUR...	.35	.49	.47	.29
PW.....	.0	.0	.0	.1
WW.....	0.	0.	0.	0.
DWPRFF....	14.570	14.570	14.571	14.573
PT2A AVG..	14.563	14.548	14.547	14.557
PT2 AVG...	.017	.021	.023	.015
DP2AVG....	2.062	2.702	2.490	1.748

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Figure A-4 *Production Log Sheet - This is a typical engine log from the production test stand printed out by the APTDAC system.*

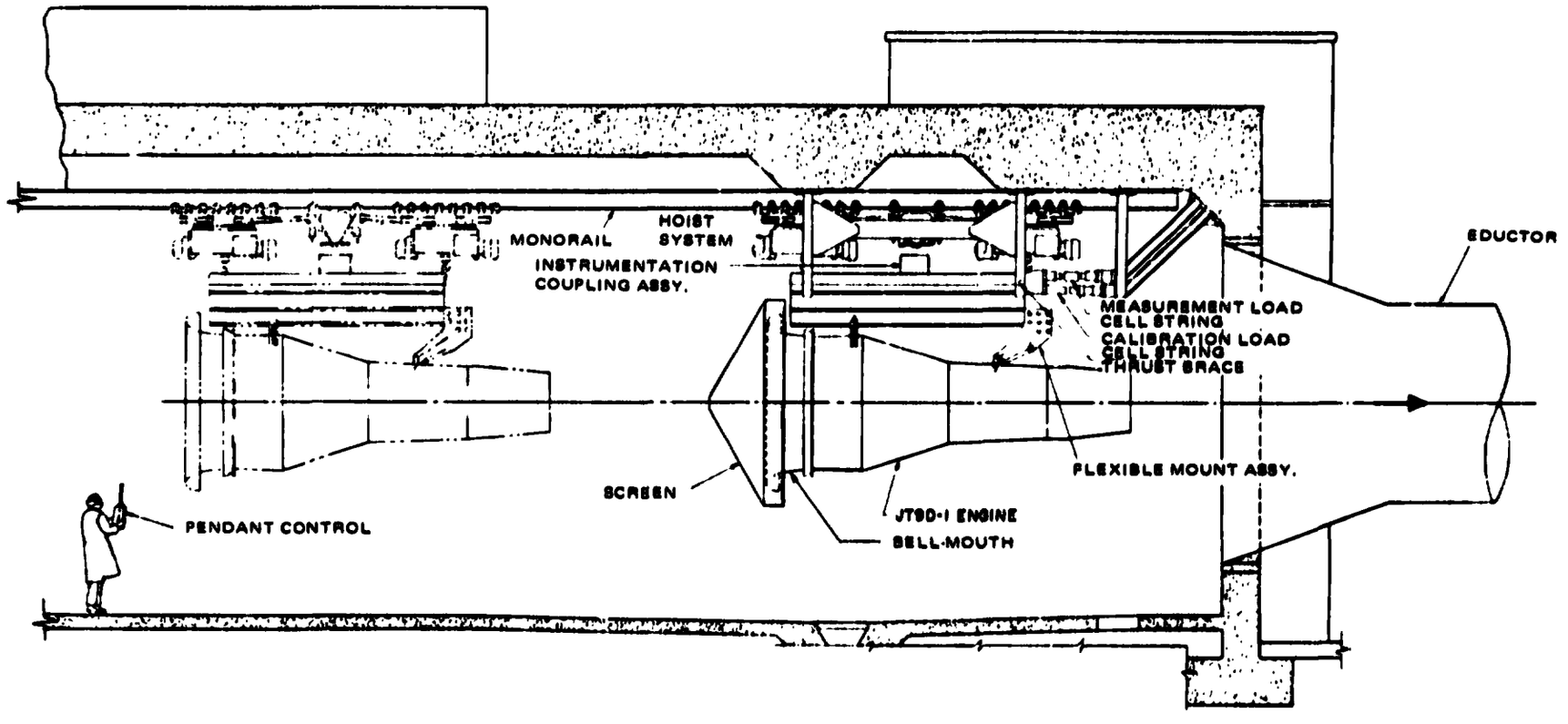


Figure A-5 *Engine Mount System - An overhead monorail engine support system provides automated engine positioning for rapid engine mounting.*

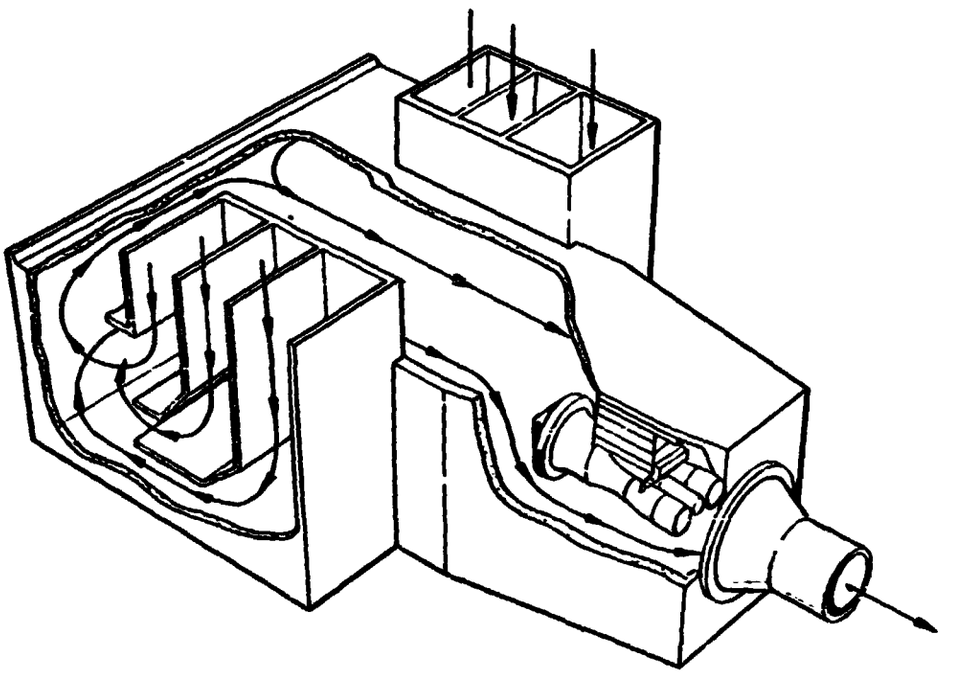


Figure A-6 ***Test Stand Inlet - The inlet system contains labyrinth baffles and acoustic treatment to suppress noise.***

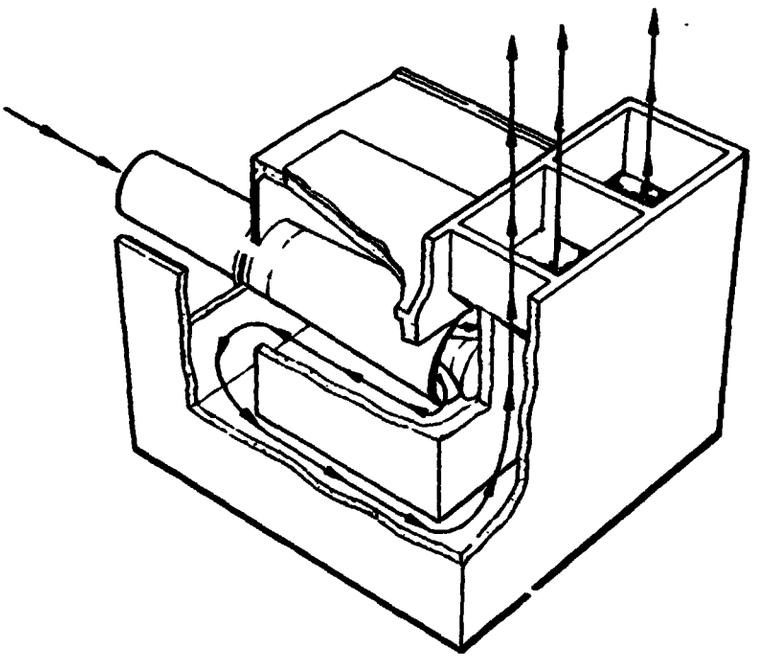


Figure A-7 ***Test Stand Exhaust System - The exhaust system is specifically designed to minimize noise emissions.***



Figure A-8 *Production Test Stand No. 4 Control Room - The controls and instrumentation needed to operate and monitor the engine are located in the control room.*

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TABLE A-I

PRODUCTION TEST INSTRUMENTATION

Parameter	No. of Probes	No. of Measurements
P_{amb}	–	1
P_{T2}	8	8
T_{T2}	8	8
P_{T2}-P_{s2}	8	8
P_{T3c}	4	1
T_{T3}	1	1
P_{s3c}	4	1
P_{s4}	1	1
T_{T4}	1	1
P_{s5}	1	1
T_{T6}	6	7
P_{T7}	6	1
T_{T7}	6	7
PLA	–	1
F_n	–	1
Vane Angle (β)	–	1
N_1	–	1
T_{T1}	–	1
N_2	–	1
CDLA	–	1
W_f	–	2
T_{Tf}	–	1
$P_{cell\ fan}$	8	1
$P_{cell\ primary}$	4	1
Spec. Humidity	–	1

The APTDAC system acquires measurements from the following ten subsystems:

- temperatures (24)
- pressures (31)
- thrust (4)
- position measurements (3)
- fuel flow (2)
- *mass oil flow (1)
- speeds (2)
- *vibration (4)
- barometric pressure (1)
- fuel density (1)
- *oil level (1)

* not required for performance measurements.

Electrical signals from these subsystems are fed into the computer which converts them into the appropriate engineering units and outputs the results to the CRT display or line printer. The integrated system of sensors, signal conditioning equipment, engine control consoles, digital computer, printer, and cathode ray tubes is designed to perform all operating functions automatically. The pneumatic and electric transducers measure approximately 80 different engine operating parameters and relay quantitative data to the computer.

The APTDAC system is designed to perform real-time data acquisition and display. The data system samples all direct current (DC) inputs (pressures, temperatures) at a scanning rate of 200 channels/second via a low-speed multiplexor which has the capability for on-line checks of the four millivolt ranges (±10, ±20, ±50, and ±5000 mv) compared to standard millivolt inputs from the data system. The channels are scanned four times and averaged. The frequency channels (fuel flow, speeds, thrust) are totalized by eight counters for a 3-second gate time and averaged. The total acquisition time for one data scan is approximately 5 seconds, and the total computer conversion and data reduction time is approximately 10 seconds. Figure A-10 shows the data flow path of the APTDAC system, and Figure A-11 is a functional block diagram of the system. The system:

- Converts inputs of frequency, pressure, and temperature to engineering units.

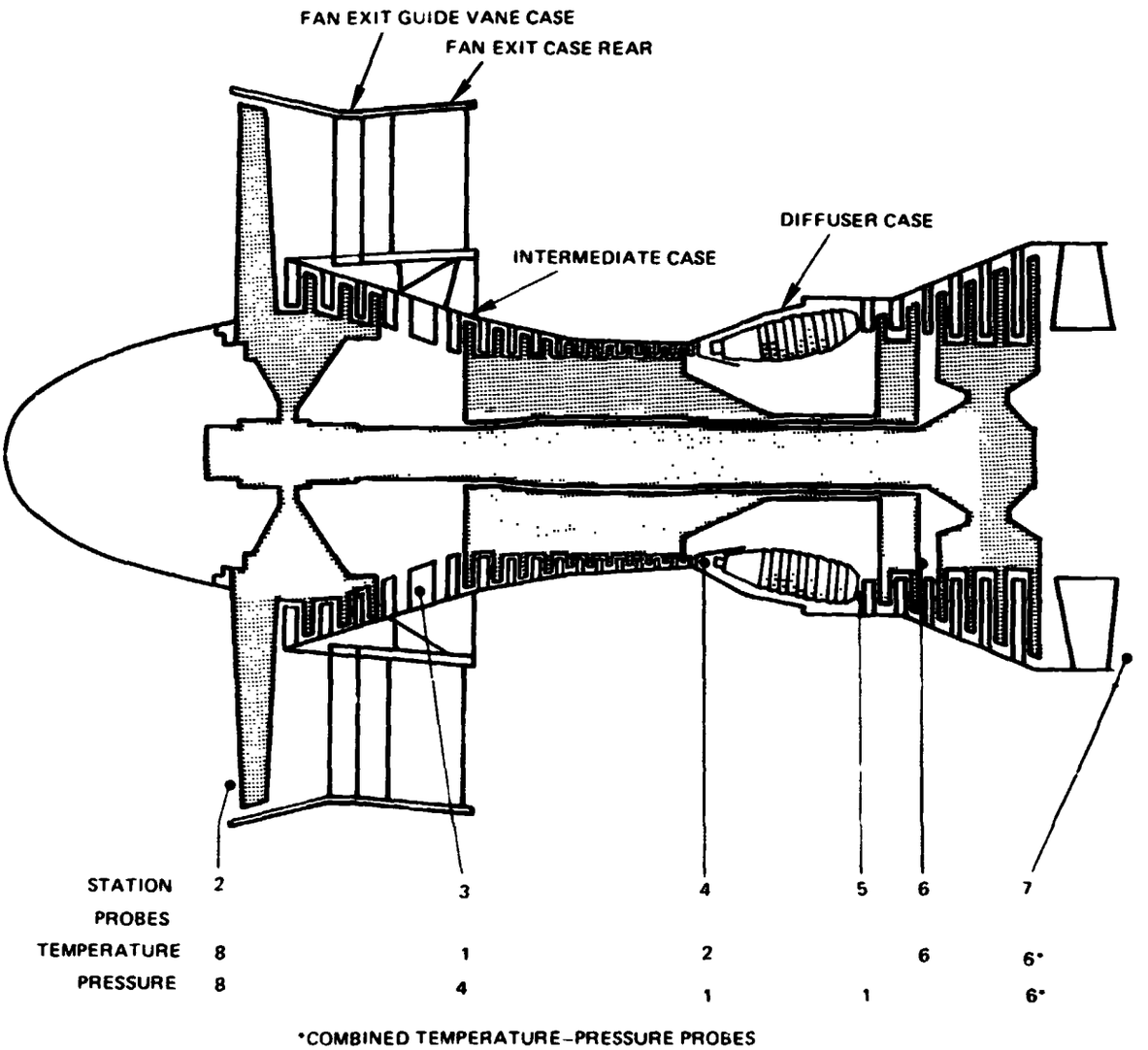


Figure A-9 *Instrumentation Probe Location - For engine calibration in the production test stand, probes are located as shown.*

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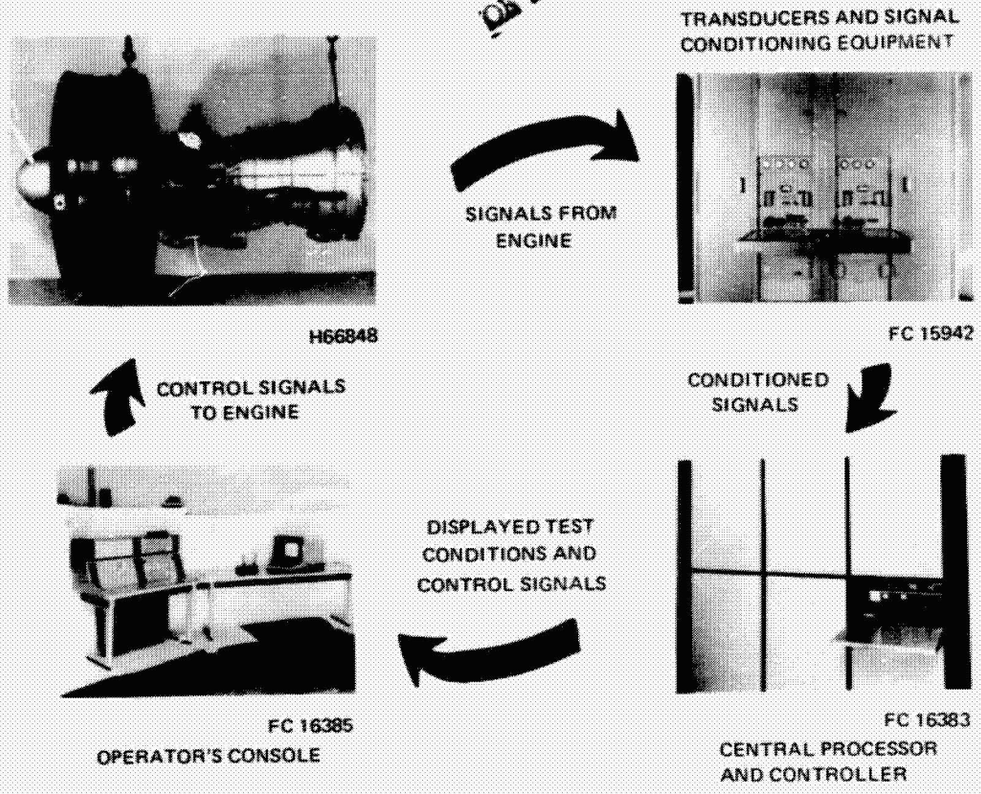


Figure A-10 *APTDAC System Data Flow Path - Engine signals are transmitted through the signal conditioner to the central controller, and processed data are transmitted to the operator's console and the engine.*

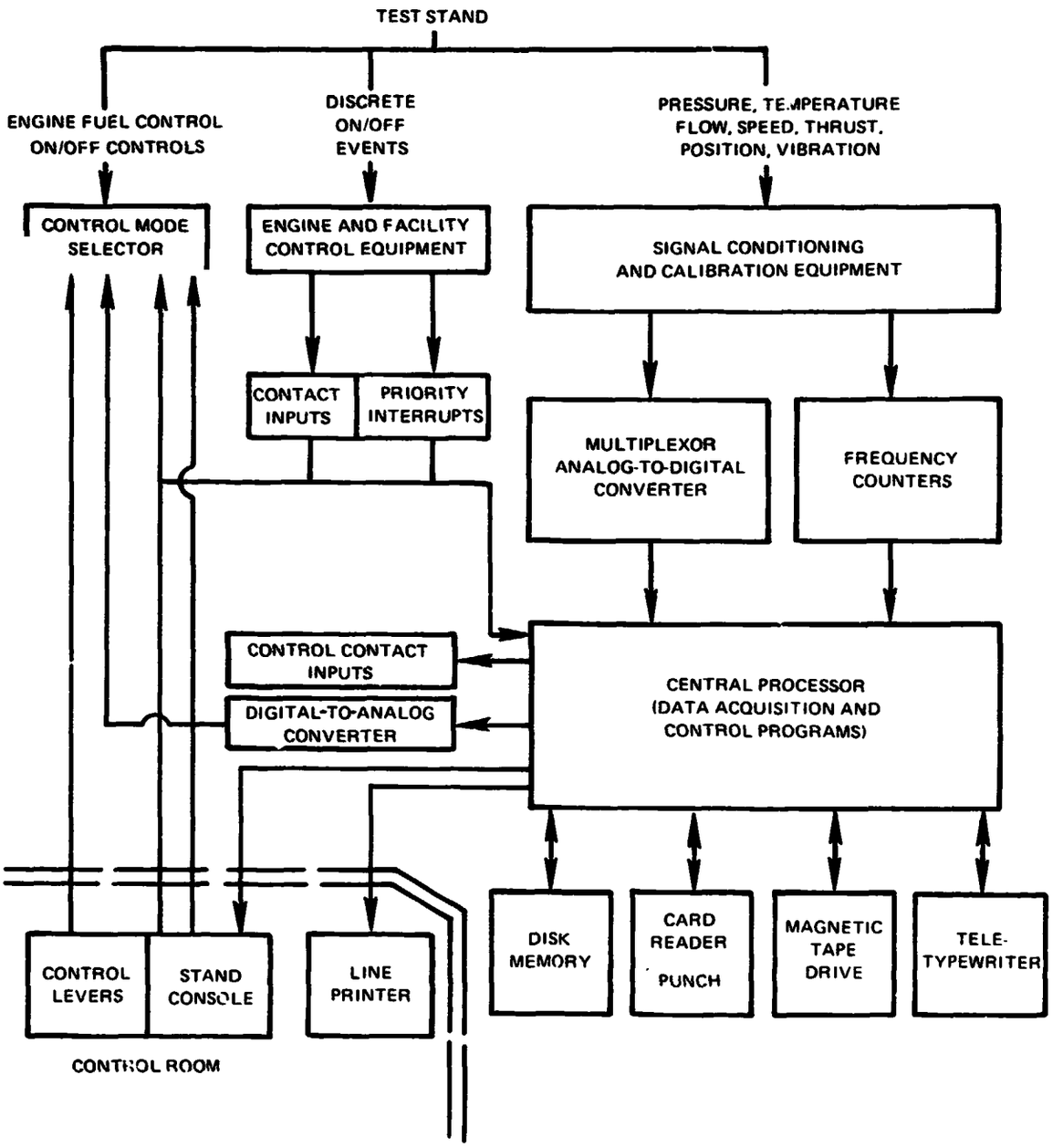


Figure A-11 *APTDAC System Functional Block Diagram - The system provides real-time data acquisition and display as well as automatic control and operation of the engine when operator control is not required.*

- Corrects data for standard day conditions.
- Computes the performance data needed to determine compliance with engine specifications.
- Compares selected parameters with established limits, activates alarms if limits are exceeded, indicates the margin if limits are not exceeded.
- Displays the data to the operator on a cathode ray tube.
- Provides printout of acquired data on command.
- Generates a magnetic tape of the data and corrected results.

The calibration procedures and parameter measurement accuracies are provided in the Instrumentation Plan, PWA-5512-4.

Test Procedures

For engine performance deterioration evaluation in the production test stand, the test-engine hardware configuration was the same as that during the engine Production Acceptance Test except for the following:

- Engine strong back serial number (S/N) 16 was not available, and S/N 1 was substituted. The impact on performance resulting from this change during this type of test was considered to be negligible.
- Primary tailpipe nozzle S/N 8 was no longer available, and nozzle S/N 12 was substituted. Nozzle S/N 12 was selected for this test based on its measured tailpipe diameter of 35.574 inches compared to a diameter of 35.575 inches for S/N 8. Again, the impact on performance resulting from this required change was considered to be negligible.

With the engine in the above configuration, the calibrations in Table A-II were conducted to systematically evaluate overall engine performance deterioration since the engine passed its Production Acceptance Test.

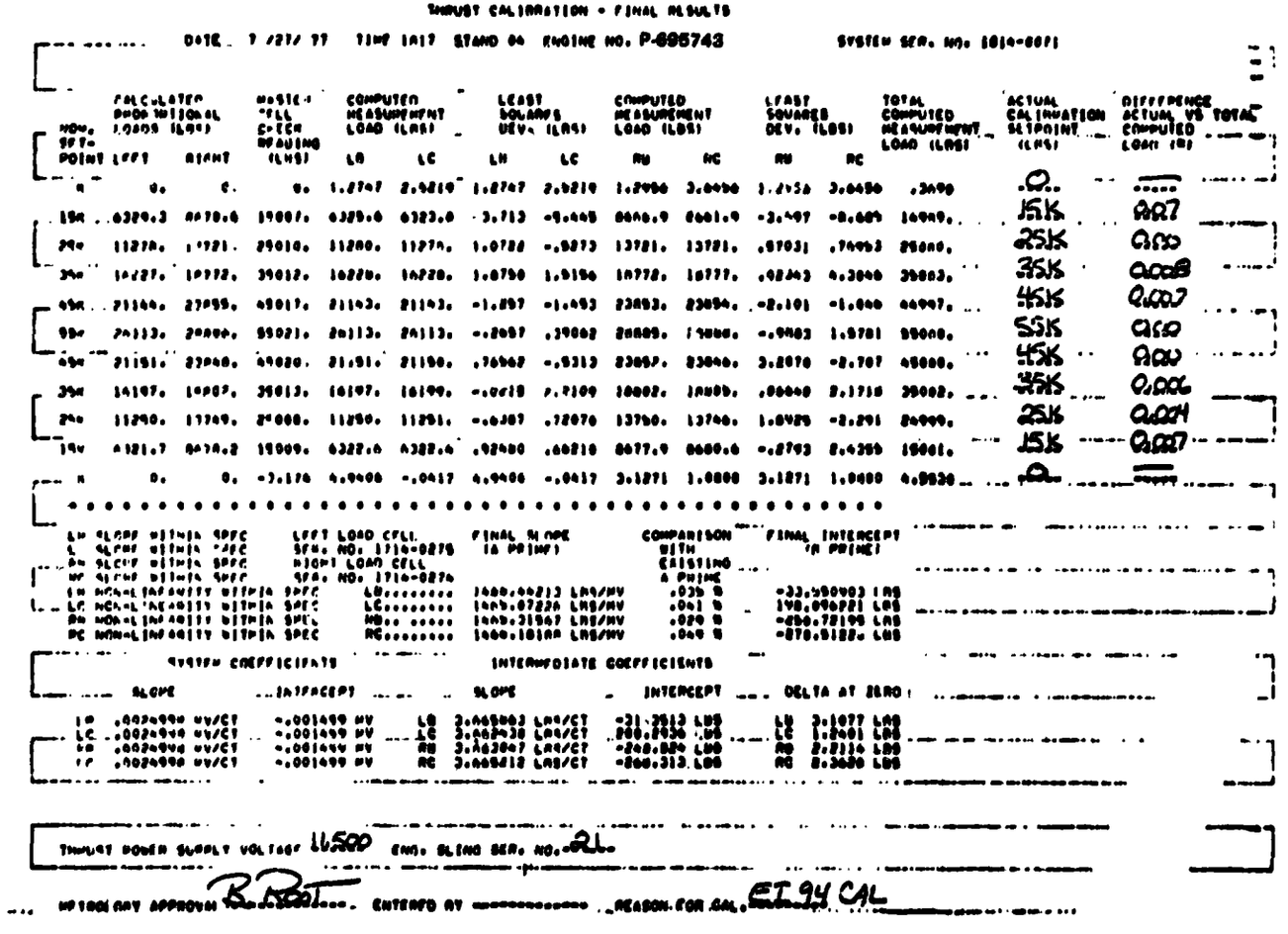
During all of these calibrations, the same general test procedures required for the Production Acceptance Test were adhered to with specific attention to the following requirements:

- Test stand instrumentation calibration was performed to ensure that no leakage or erroneous hook-up existed. Part of typical instrumentation calibration is shown in Figure A-12.
- Data were recorded at five data points spaced between take-off and the power at which the surge bleeds open.
- The data were recorded in the descending power direction.
- The engine was stabilized for a minimum of 7 minutes before recording the take-off data point and for a minimum of 5 minutes before recording the subsequent data points.
- Fuel samples were obtained prior to and after the tests to determine the specific lower heating value of the fuel during that specific test. A typical analysis of a fuel sample from the production stand is included in Appendix D.

TABLE A-II

PRODUCTION STAND TEST MATRIX

Number	Test	Purpose
1	"As-received".	To determine overall engine deterioration levels as received.
2	After Engine Vane Control (EVC) is trimmed as close as possible to the same schedule of Beta versus $N_2/\sqrt{\theta_{t2}}$ with which the engine was shipped.	To quantify the effect of any vane schedule shifts (which may have occurred due to deterioration of the gas path) on overall engine performance levels; to minimize temperature and pressure profile shifts which can occur with vane schedule shifts.
3	After gas path water wash per gas path cleaning procedure in JT9D Engine Manual.	To quantify the amounts of overall engine performance improvements that could be expected from a plain water wash.
4	After EVC is trimmed to vane schedule prior to water wash.	To eliminate any vane schedule change effects.
5	After gas path detergent wash.	To quantify the additional amounts of overall engine performance improvements that could be obtained from a detergent wash compared to improvements with a water wash and to document the overall performance deterioration since new.



THRUST CALIBRATION - FINAL RESULTS

DATE 7/27/77 TIME 1417 STAND 04 ENGINE NO. P-695743 SYSTEM SER. NO. 1014-0071

NOM. SET-POINT	CALCULATED PROPORTIONAL LOADS (LBS) LEFT	RIGHT	MASTER "FULL SCREEN" READING (LBS)	COMPUTED MEASUREMENT LOAD (LBS) LB	LC	LEAST SQUARES DEV. (LBS) LB	LC	COMPUTED MEASUREMENT LOAD (LBS) RB	RC	LEAST SQUARES DEV. (LBS) RB	RC	TOTAL COMPUTED MEASUREMENT LOAD (LBS)	ACTUAL CALIBRATION SETPOINT (LBS)	DIFFERENCE ACTUAL VS TOTAL COMPUTED LOAD (LB)
0	0.	0.	0.	1.8747	2.0219	1.8747	2.0219	1.2956	3.0490	1.2958	3.0490	.3490	0.	
15K	6329.3	6978.6	13907.	6329.0	6323.0	-3.713	-9.445	6686.9	6681.9	-3.497	-8.684	14049.	15K	951
25K	11278.	11721.	23010.	11280.	11274.	1.0788	-.9873	13781.	13781.	.87031	.74953	25000.	25K	000
35K	16227.	16772.	33012.	16228.	16220.	1.0796	1.0156	16778.	16777.	.92343	4.3848	33003.	35K	0008
45K	21144.	23855.	45017.	21143.	21143.	-1.857	-1.493	23893.	23894.	-2.101	-1.000	44997.	45K	0007
55K	26113.	29888.	55021.	26113.	26113.	-.8697	.39882	26885.	29886.	-.9483	1.9781	55000.	55K	000
45K	21151.	23868.	45020.	21151.	21150.	.76967	-.9313	23857.	23860.	3.2078	-2.787	45000.	45K	000
35K	16197.	16867.	35013.	16197.	16199.	-.0218	2.2109	16882.	16885.	.88648	3.1718	33002.	35K	0006
25K	11290.	11749.	23000.	11290.	11291.	-.6387	.72878	13750.	13748.	1.8429	-2.291	24999.	25K	0004
15K	6321.7	6978.2	13909.	6322.6	6322.6	.92488	.68218	6677.9	6680.6	-.8793	8.4289	15001.	15K	0007
0	0.	0.	-3.176	4.9488	-.0417	4.9486	-.0417	3.1871	1.8888	3.1871	1.8488	4.9838	0.	

	SPEC	LEFT LOAD CELL SER. NO. 1710-0275	FINAL SLOPE (A POINT)	COMPARISON WITH EXISTING A POINT	FINAL INTERCEPT (A POINT)
LM	SLOPE WITHIN SPEC				
L	SLOPE WITHIN SPEC				
RM	SLOPE WITHIN SPEC	RIGHT LOAD CELL			
R	SLOPE WITHIN SPEC	SER. NO. 1710-0274			
LM	NORMAL INFINITY WITHIN SPEC	LB.....	1488.88213 LBS/MV	.036 %	-33.858983 LBS
LC	NORMAL INFINITY WITHIN SPEC	LC.....	1485.87228 LBS/MV	.041 %	148.898881 LBS
RM	NORMAL INFINITY WITHIN SPEC	RB.....	1488.31967 LBS/MV	.020 %	-858.781998 LBS
RC	NORMAL INFINITY WITHIN SPEC	RC.....	1488.18188 LBS/MV	.048 %	-878.81888 LBS

SYSTEM COEFFICIENTS SLOPE	INTERCEPT	INTERMEDIATE COEFFICIENTS SLOPE	INTERCEPT	DELTA AT ZERO
LB .0024998 MV/CT	-.0014998 MV	LB 3.4698863 LBS/CT	-31.3813 LBS	LB 3.1877 LBS
LC .0024998 MV/CT	-.0014998 MV	LC 3.4628938 LBS/CT	888.8836 LBS	LC 1.2481 LBS
RB .0024998 MV/CT	-.0014998 MV	RB 3.4628867 LBS/CT	-248.888 LBS	RB 2.7114 LBS
RC .0024998 MV/CT	-.0014998 MV	RC 3.4688818 LBS/CT	-888.313 LBS	RC 8.3688 LBS

THRUST POWER SUPPLY VOLTAGE 11.500 CAL. BLOCK SER. NO. 21

METROLOGY APPROVAL R Root ENTERED BY ---------- REASON FOR CAL. ET 94 CAL

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Figure A-12 *Typical Instrumentation Calibration Results - The thrust system calibration shows that the system is operating within specification limits.*

EXPERIMENTAL TEST STAND

Test Facility

The test facility used to document specific module/component performance deterioration was test stand X-8 at Pratt & Whitney Aircraft's East Hartford Engineering Facilities. Test stand X-8, shown schematically in Figure A-13, is a gas turbine engine test facility designed to test large, high bypass ratio turbofan and turbojet development engines at static sea level conditions. The test stand ejector is designed to handle a total air flow of 3600 pounds/second at 400°F, and a primary inlet (engine and fan) air flow of 2000 pounds/second. Air flows are based on normally acceptable pressure drops; higher air flows can be achieved if the corresponding increase in pressure loss is acceptable for the particular application.

The stand is constructed of reinforced concrete. The air inlet and test cell compartment have a square cross-section. Atmospheric air is admitted at one end of the test cell through a horizontal full area inlet and exhausted upward at the opposite end. Noise reduction is accomplished at the inlet by means of 42-percent sound stream insulation and in the exhaust by passing the air through thirty-nine inch I.D. 20-ft length vertical perforated corten steel tubes covered with 14 mesh monel glass cloth. The area between the tubes is packed with fiberglass to absorb the sound energy. Secondary air for engine cooling is admitted to the cell through a 330 sq. ft. roof opening, the inlet section of which is composed of 51.5 percent open area splitters for sound attenuation.

The test engine is mounted from a flexure supported overhead thrust measurement platform shown schematically in Figure A-14. Thrust is measured by a strain-gage load cell located on the platform centerline. Provisions are also incorporated in the system for a calibration load cell train located concentrically with the primary load cell.

The engine is connected to the thrust platform through a flexible engine mount adapter which is attached to, and transported with, the engine to the test stand. Instrumentation can be installed on the engine prior to delivery to the test stand and connected to panels provided for this purpose on the flexible mounting structure. After the engine is mounted in the stand, jumpers are installed from these panels to matching number panels permanently installed in the stand. Quick disconnect hookups are designed for each instrument to permit rapid installation. These provisions are shown in Figure A-15. The stand panels are permanently connected to the appropriate readout equipment or data transmitting devices located in the Control Room, Automatic Data System Room, or a panel outside the stand which may be connected to special Instrumentation Vans. During operation, engine exhaust gases are directed into a cylindrical duct. There they are mixed with cooling air aspirated into the test cell by the ejector action of the engine exhaust stream as it enters the duct. There they are mixed with cooling air aspirated into the test cell by the ejector action of the engine exhaust stream as it enters the duct. Length of the cylindrical duct section is adjustable over a range of 8 ft. 9 in. so that it may be positioned in the optimum location relative to the engine nozzles. After mixing, the gases are ducted into an exhaust plenum into which they are diffused through perforations in the aft portion of the duct. In addition, this system is provided with an ejector spoiling device to modulate the pumping action, and remote controlled secondary air inlet dampers. These devices allow setting of the cell pressure (PT2) to cell tailpipe pressure (P cell-TP). From the plenum the gases flow to the exterior of the building, passing through the exhaust silencer. Primary

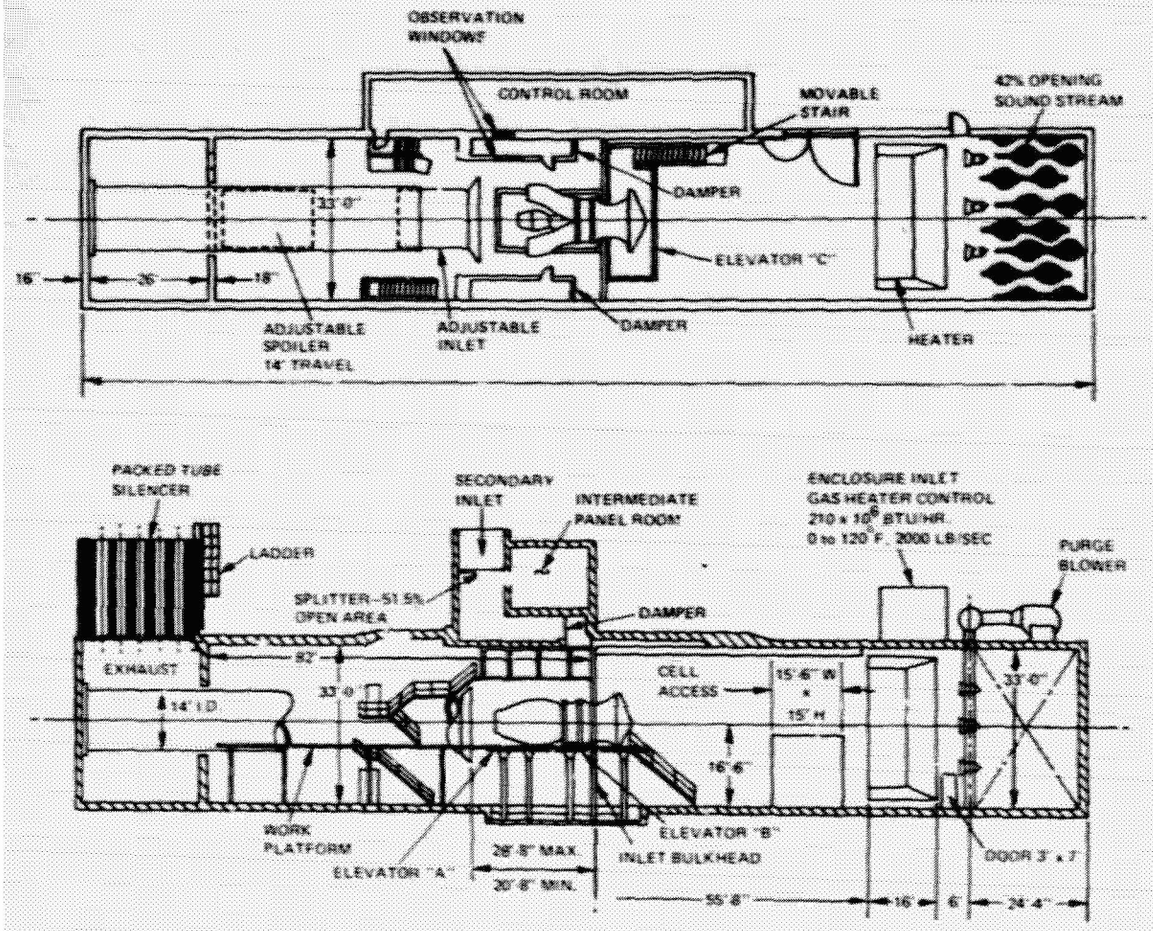


Figure A-13 *X-8 Sea Level Engine Test Stand - This experimental test stand was used to measure component/module performance.*

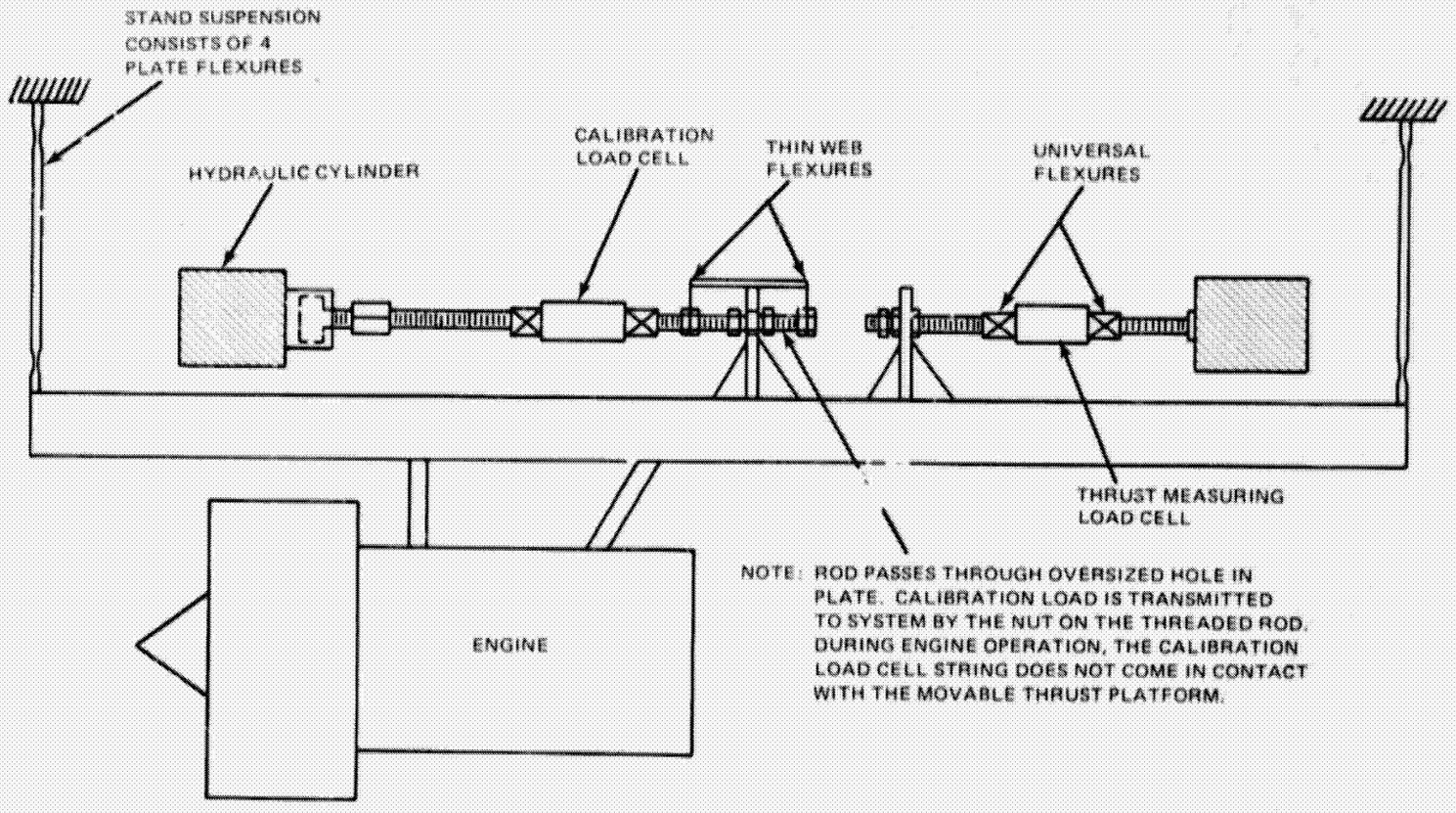


Figure A-14 *X-8 Test Stand Thrust Measurement System - The flexure supported overhead thrust measurement platform provides good accuracy.*

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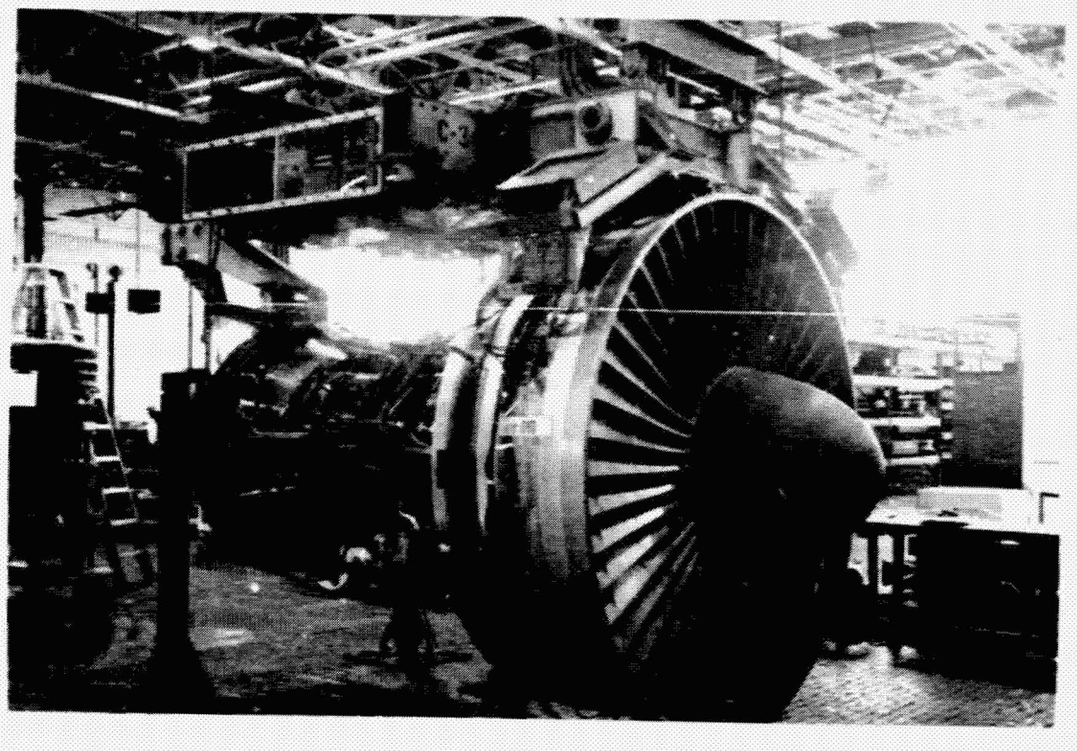


Figure A-15 *Engine Being Prepared for Test - The mounting structure and quick disconnect panels permit fast installation in the test stand.*

air entering at the front of the test cell is prevented from passing around the engine by a steel bulkhead. This bulkhead blocks the full cross-section of the cell at the plane of the engine inlet.

Services available to this stand include: 110 psig shop air primarily for instrumentation, controls, cooling, and engine starting; 110 and 440 volt 60 Hz A.C.; 400 Hz A.C.; and 24 volt D.C. electrical power supplies; 125 psig industrial water; test cell water fog fire system; 25 psig and 140 psig steam; high pressure (750 psig) demineralized water; fuel supplies; and a hydraulic system to operate the test cell work platforms.

The controls and instrumentation necessary to operate the test engine and monitor selected performance parameters are located in an adjacent control room, shown in Figure A-16. Continual visual observation of the engine is possible through a window in the test stand wall.



Figure A-16 *X-8 Test Stand Control Room - The controls and instrumentation needed to operate and monitor the engine are located in the control room.*

Instrumentation and Data Acquisition System

In experimental test stand X-8, the engine was tested with expanded instrumentation to measure specific module/component performance deterioration levels. Table A-III lists the parameters that were measured, and Figure A-17 shows the location of the instrumentation probes in the engine.

The test stand (X-8) has direct access to the Pratt & Whitney Aircraft Steady State Data System (SSDS) which is controlled by an on-line Honeywell Model DDP-516 computer system. The following paragraphs present a description of the SSDS, its capacity, and modes of operation as the system is utilized on the test stand. Figure A-18 is a block diagram of the data system indicating the various interfaces of the system.

The Steady State Data System consists of a pressure measuring subsystem, an electrical subsystem, data printers, control consoles, and a central computer. The system is capable of handling 480 pressure signals, 350 temperature signals, 10 position signals, and 16 frequency signals.

The subsystem receives, conditions, sequences, digitizes, and transmits pressure, temperature, and frequency data to the computer. Pneumatic transducers measure the engine operating pressures and relays the quantitative data to the pressure subsystem. The Uniform Temperature Reference System measures the engine operating temperatures (in millivolts) and relays the signals to the electrical subsystem. The frequency counter records the frequencies for five 10-second intervals during the data acquisition.

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TABLE A-III

EXPERIMENTAL TEST INSTRUMENTATION

Parameter	No. of Probes	No. of Measurements
P_{amb}	–	1
P_{T2}	8	8
P_{T2}-P_{s2}	8	8
T_{T2}	24	24
$P_{T2.4}$	8	64
$T_{T2.4}$	8	64
$P_{T2.6}$	4	20
$T_{T2.6}$	4	20
P_{T3}	8	21
P_{s3}	4	1
T_{T3}	5	21
P_{T4}	4	12
P_{s4}	1	1
T_{T4}	7	15
P_{s5}	1	1
P_{T6}	3	3
T_{T6}	3	3
P_{T7}	6	1
T_{T7}	6	7
PLA	–	1
F_n	–	2
Vane Angle (β)	–	1
N_1	–	1
N_2	–	1
W_f	–	2
T_{Tf}	–	1
T_{T1}	–	1
CDLA	–	1
$P_{cell\ fan}$	8	8
$P_{cell\ primary}$	4	4
Spec. Humidity	–	1

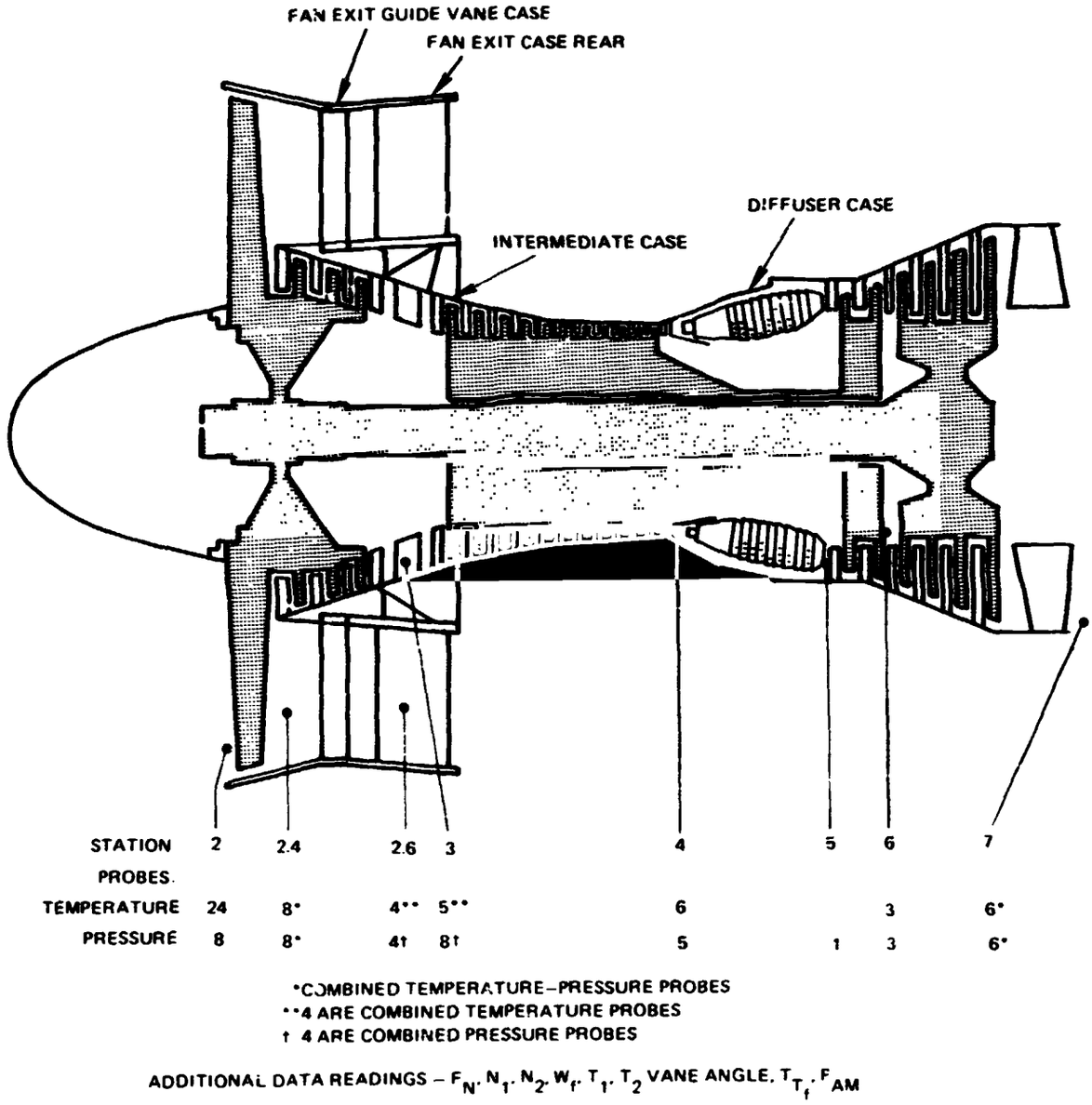


Figure A-17 *Instrumentation Probe Location - For engine calibration in the experimental test stand, probes are located as shown.*

The on-line computer:

- Receives acquisition signal from test stand control panel and triggers appropriate equipment for data acquisition.
- Receives the digitized pressure, temperature, and frequency inputs from the subsystem.
- Applies system corrections to these inputs.
- Applies instrumentation corrections such as wire calibration corrections for T_{T2} and $T_{T2.4}$ and probe recovery corrections for $T_{T2.4}$.
- Converts inputs to engineering units.
- Performs limited performance calculations.

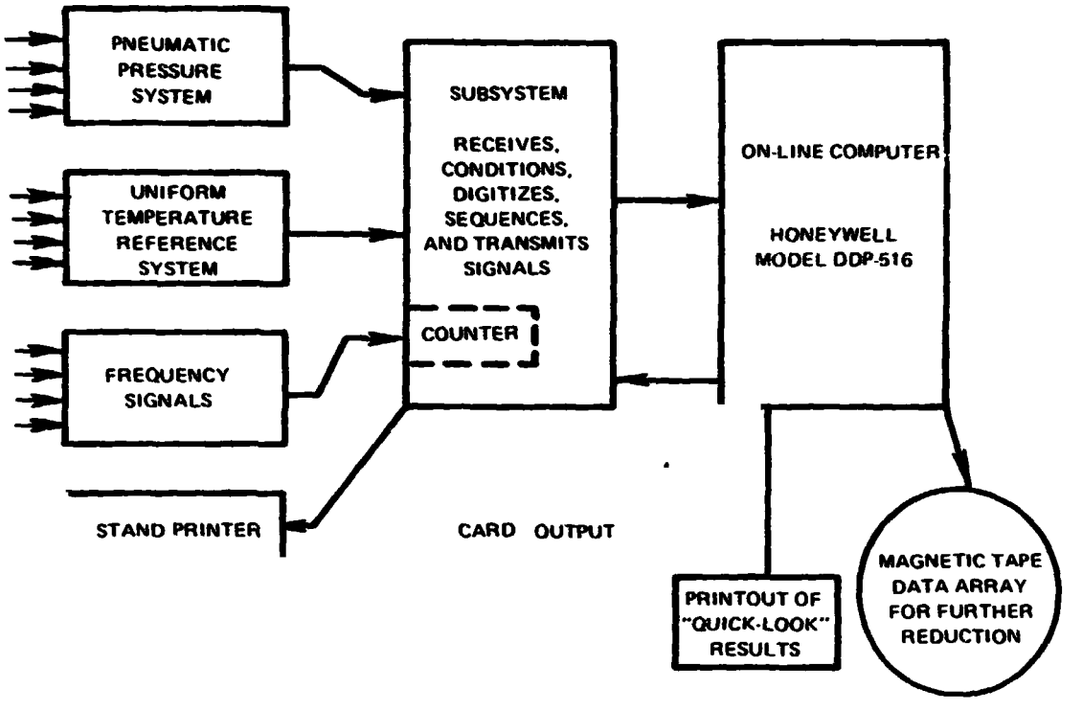


Figure A-18 *Block Diagram of the Steady State Data System - Interfaces of the various subsystems and the on-line computer are defined.*

- Generates magnetic tape and/or card output of engineering units for further data reduction by an off-line computer.
- Generates "Quick-Look" printout at central.
- Triggers control of stand printer and sends output of data acquisition to test stand for "Quick-Look" printout.

Detailed calibration procedures and parameter measurement accuracies are provided in the Instrumentation Plan, PWA-5512-4.

Test Procedure

Prior to the test program in Experimental Engineering test stand X-8, the engine was modified with nonproduction Bill-of-Materials cases to allow the installation of additional performance measurement instrumentation probes. The cases changed for this test were the fan exit guide vane case, the fan exit case rear, the intermediate case, and the diffuser case (see Figure A-17).

Special test hardware, such as the fan and primary exit nozzles, was installed for this test. The fan nozzle area was sized at 21.3 square feet to simulate a Bill-of-Materials average fan nozzle area of 20.04 square feet. The primary nozzle area was sized at 6.92 square feet relative to a Bill-fo-Materials primary nozzle area of 6.6 square feet (see Figure A-19). These nozzle sizes were calculated and sized to compensate for the pressure losses through out the engine resulting from the extensive instrumentation probes creating blockage in the engine flow passages.

The engine was mounted in X-8 test stand where all of the engine instrumentation was connected to the stand system by quick disconnect fittings for monitoring by the Steady State Data System. The instrumentation system was pressure checked and verified to ensure data validity during the test.



Figure A-19 *Engine Primary and Fan Discharge Nozzles - These nozzles are specially sized to compensate for instrumentation probe blockage.*

During this calibration, particular attention was devoted to the following steps:

- A thrust meter zero calibration was made before the test, and an "as-is" thrust meter calibration was made after the test. Figure A-20 is a typical thrust meter calibration.
- The two Pratt & Whitney Aircraft Cox Meters were calibrated before the test. A typical Cox Meter calibration is shown in Figure A-21.
- A fuel sample was taken and forwarded to the Materials Engineering Research Laboratory (MERL) before and after the calibration for lower heating value and specific gravity analyses. A typical analysis of a fuel sample from the experimental test stand is shown in Appendix D.
- The JT9D-7A(SP) engine operating limits were observed while conducting the test. Figure A-22 illustrates typical JT9D operating limits.
- The humidity limits of Figure A-23 were observed for this test.
- The stator vanes were trimmed to within limits of the 241-vane schedule prior to test.
- The engine was stabilized for 7 minutes at each point in the calibration.

One ten-point steady state performance calibration was conducted at the thrust levels shown in Table A-IV to document the deteriorated levels of the individual module/component performance.

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Pratt & Whitney Aircraft

TEST STAND THRUST SYSTEM CALIBRATION
APPLICABLE IS&P NUMBER
3:3205:1

STAND X-8
BRIDGE A
K 6
DATE 2-10-71

EXPERIMENTAL ENGINEERING STANDARDS LABORATORY

CALIBRATION THRUST-LBS (1)	THRUST METER LBS (2)	FREQUENCY HZ (3)	FREQ X K (4)	CORRECTION (1)-(4) (5)		AVE CORR. (6)	HYSTERESIS (7)
0	0	0	0	0	0	0	0
12	11994	1998	11988	+12	+18	+15	6
24	23970	1995	23970	+30	+30	+30	0
36	35985	1997	35982	+18	+24	+21	6
48	48000	8000	48000	0	0	0	0
60	60016	10005	60030	-30	-18	-24	12
61	61017	10162					
60	60010	10003	60018				
48	47995	8000	48000				
36	35982	5996	35976				
24	23977	3995	23970				
12	11996	1997	11982				
0	0	0	0				

TOLERANCE FOR CORRECTED CAL: COL (6). 0.1% F.S
COL (7). 0.1% F.S.

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THRUST HISTORY DATA

STAND	ENGINE TYPE	ENGINE NUMBER	BRIDGE	K	DATE	TIME	EXCITATION	MV. R-CALS 0	MV. R-CALS #1	MV. R-CALS #2	MV. R-CALS #3	FREQ. R-CALS 0	FREQ. R-CALS #1	FREQ. R-CALS #2	FREQ. R-CALS #3	LOAD CELL TEMP	CAL CELL R-CAL	CAL	CAL CELL CODE	F.S. (K)	ASSIG
1	4	9	11		16	22	26	33	36	41	46	51	54	58	62	66	69	71	75	78	81
X-8	7T-7	0911	1V3	A	6	2/6/71	1630	48451	26830	23663	00000	80631	11365	11365	00000			MV	6	0	

	POINT #1, 7 FREQ	POINT #1, 7 CAL THRUST	POINT #2, 8 FREQ	POINT #2, 8 CAL THRUST	POINT #3, 9 FREQ	POINT #3, 9 CAL THRUST	POINT #4, 10 FREQ	POINT #4, 10 CAL THRUST	POINT #5, 11 FREQ	POINT #5, 11 CAL THRUST	POINT #6, 12 FREQ	POINT #6, 12 CAL THRUST	MAX PT FREQ	MAX PT CAL THRUST
1	11		21		31		41		51		61		71	

APPROVAL: TEST ENGINEER _____
INST. LAB. FOREMAN _____
DATA RECORDED BY JD & NC.

Figure A-20 *Typical Thrust Meter Calibration - These calibrations are made both before and after the engine test.*

FUEL FLOWMETER RATIO CALIBRATION 08:10 JUN 28,'77
BASELINE CALIBRATION
FLOWMETER SERIAL NO:19376 NOMINAL K = 1168.3 CY/GAL
CAL DATE 06/27/77 METER SIZE 20 FUEL JET4 CAL NO. 0 VISCOSITY 1.670 SPEC GRAV .7979 TEMP 79.0 F

HZ	K CY/GAL	HZ	K CY/GAL	HZ	K CY/GAL	HZ	K CY/GAL	HZ	K CY/GAL	HZ	K CY/GAL	HZ	K CY/GAL	HZ	K CY/GAL	HZ	K CY/GAL
77*	1159.29	81	1159.39	125	1156.86	169	1155.09	213	1152.36	320	1147.91	760	1168.81	1200	1168.73	1600	1168.66
78	1159.42	82	1159.24	126	1156.96	170	1155.02	214	1152.30	330	1147.99	770	1168.83	1210	1168.74	1650	1168.66
79	1159.60	83	1159.10	127	1156.83	171	1154.96	215	1152.24	340	1147.98	780	1168.86	1220	1168.74	1660	1168.65
80	1159.79	84	1158.95	128	1156.82	172	1154.90	216	1152.18	350	1148.02	790	1168.89	1230	1168.74	1670	1168.65
81	1159.97	85	1158.90	129	1156.81	173	1154.84	217	1152.11	360	1148.06	800	1168.92	1240	1168.74	1680	1168.64
82	1160.15	86	1158.66	130	1156.80	174	1154.78	218	1152.05	370	1148.10	810	1168.94	1250	1168.74	1690	1168.63
83	1160.34	87	1158.51	131	1156.79	175	1154.71	219	1151.99	380	1148.14	820	1168.97	1260	1168.75	1700	1168.63
84	1160.52	88	1158.37	132	1156.77	176	1154.65	220	1151.93	390	1148.17	830	1168.60	1270	1168.75	1710	1168.62
85	1160.70	89	1158.22	133	1156.76	177	1154.59	221	1151.87	400	1148.21	840	1168.63	1280	1168.75	1720	1168.62
86	1160.88	90	1158.07	134	1156.75	178	1154.53	222	1151.80	410	1148.25	850	1168.65	1290	1168.75	1730	1168.61
87	1161.07	91	1157.93	135	1156.74	179	1154.47	223	1151.74	420	1148.29	860*	1168.67	1300	1168.75	1740	1168.61
88	1161.25	92	1157.78	136	1156.73	180	1154.40	224	1151.68	430*	1148.33	870	1168.67	1310	1168.75	1750	1168.60
89	1161.43	93	1157.64	137	1156.72	181	1154.34	225	1151.62	440	1148.30	880	1168.68	1320	1168.76	1760	1168.60
90	1161.62	94	1157.49	138	1156.70	182	1154.28	226	1151.56	450	1148.27	890	1168.68	1330	1168.76	1770	1168.59
91	1161.80	95	1157.34	139	1156.69	183	1154.22	227	1151.49	460	1148.24	900	1168.68	1340	1168.76	1780	1168.59
92	1161.98	96*	1157.20	140	1156.68	184	1154.16	228	1151.43	470	1148.21	910	1168.68	1350	1168.76	1790	1168.58
93	1162.16	97	1157.19	141	1156.67	185	1154.09	229	1151.37	480	1148.18	920	1168.68	1360	1168.76	1800	1168.57
94	1162.35	98	1157.17	142	1156.66	186	1154.03	230	1151.31	490	1148.15	930	1168.68	1370	1168.77	1810	1168.57
95	1162.53	99	1157.16	143	1156.65	187	1153.97	231	1151.25	500	1148.12	940	1168.69	1380	1168.77	1820*	1168.56
96	1162.71	100	1157.15	144*	1156.63	188	1153.91	232	1151.19	510	1148.09	950	1168.69	1390	1168.77		
97*	1162.90	101	1157.14	145	1156.57	189	1153.85	233	1151.12	520	1148.06	960	1168.69	1400	1168.77		
98	1163.75	102	1157.13	146	1156.51	190	1153.79	234	1151.06	530	1148.03	970	1168.69	1410	1168.77		
99	1162.60	103	1157.11	147	1156.45	191	1153.72	235	1151.00	540	1148.00	980	1168.69	1420	1168.77		
100	1162.46	104	1157.10	148	1156.39	192	1153.66	236	1150.94	550	1147.97	990	1168.70	1430*	1168.78		
101	1162.31	105	1157.09	149	1156.32	193	1153.60	237	1150.88	560	1147.94	1000	1168.70	1440	1168.77		
102	1162.16	106	1157.08	150	1156.26	194	1153.54	238	1150.81	570*	1147.91	1010	1168.70	1450	1168.77		
103	1162.02	107	1157.07	151	1156.20	195	1153.48	239	1150.75	580	1147.92	1020	1168.70	1460	1168.76		
104	1161.87	108	1157.06	152	1156.14	196	1153.41	240	1150.69	590	1147.95	1030	1168.70	1470	1168.75		
105	1161.73	109	1157.04	153	1156.08	197	1153.35	241	1150.63	600	1147.97	1040	1168.71	1480	1168.75		
106	1161.58	110	1157.03	154	1156.01	198	1153.29	242	1150.57	610	1148.00	1050	1168.71	1490	1168.74		
107	1161.43	111	1157.02	155	1155.95	199	1153.23	243	1150.50	620	1148.03	1060	1168.71	1500	1168.74		
108	1161.29	112	1157.01	156	1155.89	200	1153.17	244	1150.44	630	1148.05	1070	1168.71	1510	1168.73		
109	1161.14	113	1157.00	157	1155.83	201	1153.10	245	1150.38	640	1148.08	1080	1168.71	1520	1168.73		
110	1161.00	114	1156.99	158	1155.77	202	1153.04	246	1150.32	650	1148.11	1090	1168.71	1530	1168.72		
111	1160.85	115	1156.97	159	1155.70	203	1152.98	247	1150.26	660	1148.14	1100	1168.72	1540	1168.72		
112	1160.70	116	1156.96	160	1155.64	204	1152.92	248	1150.19	670	1148.16	1110	1168.72	1550	1168.71		
113	1160.56	117	1156.95	161	1155.58	205	1152.86	249	1150.13	680	1148.19	1120	1168.72	1560	1168.71		
114	1160.41	118	1156.94	162	1155.52	206	1152.79	250	1150.07	690	1148.22	1130	1168.72	1570	1168.70		
115	1160.27	119	1156.93	163	1155.46	207	1152.73	260	1149.45	700	1148.24	1140	1168.72	1580	1168.69		
116	1160.12	120	1156.92	164	1155.40	208	1152.67	270	1148.83	710	1148.27	1150	1168.73	1590	1168.69		
117	1159.97	121	1156.90	165	1155.33	209	1152.61	280	1148.21	720	1148.30	1160	1168.73	1600	1168.68		
118	1159.83	122	1156.89	166	1155.27	210	1152.55	290*	1147.79	730	1148.33	1170	1168.73	1610	1168.68		
119	1159.68	123	1156.88	167	1155.21	211	1152.49	300	1147.83	740	1148.35	1180	1168.73	1620	1168.67		
120	1159.53	124	1156.87	168	1155.15	212	1152.42	310	1147.87	750	1148.38	1190	1168.73	1630	1168.67		

$$PPH = \frac{30018.381 \times (SP.GR. - 0.0012171) \times HZ}{CPG}$$

CURVE NO: 0
3/18399

FLOW RANGE 764.49 TO 37889.00 PPH * INDICATES AN INPUT POINT

PRATT & WHITNEY AIRCRAFT CALIBRATION SYSTEM
8-22-77
2-22-78
3:30 PM

Figure A-21 Typical Cox Meter Calibration - These fuel flow meters were calibrated before the engine test.

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2.4 MAX. SAFE OPERATING SPEEDS: 3750 N1 and 8000 N2 rpm obs. must not be exceeded without Engineering approval.

2.5 VIBRATION: The maximum allowable vibration levels (single amplitude) at all thrust levels are:

Intermediate Case	.0015 inches
Diffuser Case	.002 inches
Turbine Case	.002 inches

2.6 SMOKE: The smoke values at the required thrust levels shall not exceed the following:

Von Brand Index	20

2.7 SEAL LEAKAGE LIMITS: During acceptance test, seal leakages shall be collected in individual containers, and leakages shall not exceed the following limits:

Fuel Pump	30 cc/hr
EVC and 3.0 Bleed Actuator	
Converter Valve and Surge Detector	15 cc/hr total
Hydraulic Pump Drive	10 cc/hr
Fuel/Oil Cooler	No measurable leakage

2.8 WATER SYSTEM: (Applies to Engines Designated Wet)

Inlet water pressure (Pw) to the control port of the water regulator shall be between 519 and 735 psig, and the water flow range (Ww) shall be 26,000 to 30,000 lbs/hr. Water supplied to the water injection control must be demineralized and the total dissolved and undissolved solids content must not be greater than 10 parts per million total solids. Particle size of undissolved solids shall be no greater than will pass through a 40 micron filter.

Figure A-22 *Typical Test Engine Operating Limits - JT9D-7A(SP) operating limits were strictly observed throughout the engine test.*

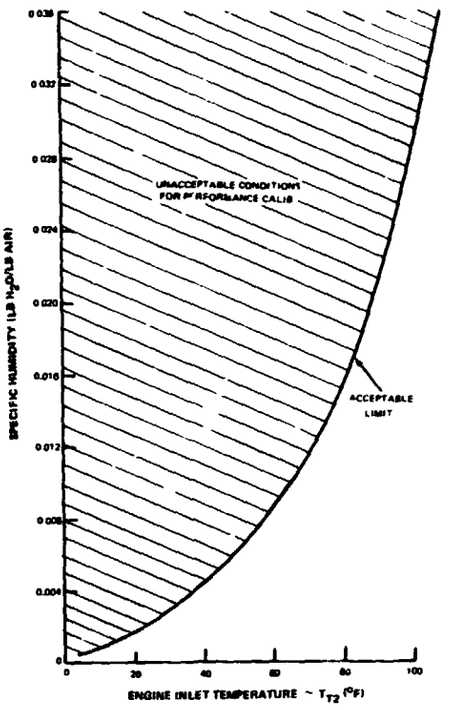


Figure A-23 *Specific Humidity Limitation for Experimental Engine Calibration - The humidity limitation was observed for the engine test.*

TABLE A-IV

EXPERIMENTAL STAND TEST MATRIX

Point Number	Thrust (pounds)
1	46,000
2	44,000
3	42,000
4	40,000
5	38,000
6	36,000
7	34,000
8	32,000
9	44,000*
10	38,000*

*These points were rerun as a repeatability check.

TEARDOWN PROCEDURE

Following the performance calibration test in X-8 test stand, an analytical teardown and inspection of the engine was conducted at Pratt & Whitney Aircraft's Southington Service Center. The intent of this effort was to inspect, measure, and analyze various hardware in the engine and to assess the contribution of the hardware condition to the short term performance deterioration of the engine.

Specific detailed instructions were given to the Inspection Department at the Service Center to take certain measurements in a particular sequence so that none of the measurements would be altered or destroyed prior to going on to the next step. After a few of the

detailed measurements and observations had been made, it became apparent that measuring all of the parts as originally intended would become redundant and that little additional information would be obtained; for example, fan blade length, full high-pressure compressor deblading, etc. Instructions were modified, as the teardown proceeded, generally as a result of the good condition of the parts in the engine. All, or a sampling, of the hardware that had an influence on engine performance deterioration was inspected and measured. Appendix B presents a detailed description of the teardown procedure.

DATA REDUCTION AND ANALYSIS PROCEDURE

Once the data has been obtained from actual engine testing, the data are ready for further reduction and processing for detailed analyses. Both the APTDAC and SSDS systems provide a magnetic tape and/or card record of the card and field arrays along with a printout of the engine calibration data. Sample printouts from the APTDAC and SSDS systems are shown in Figures A-24 and A-25, respectively. The magnetic tape and/or cards are then loaded into the IBM 370 computer (see Figure A-26) where the data is then edited and profiled to reject erroneous readings and inputs new values for erroneous readings. In the production test stand (APTDAC), little or no editing or profiling is required, primarily because of the limited instrumentation. Once the data is in the IBM 370 computer, any changes or corrections to the data can be done from a remote terminal or by key punching new cards. Corrections that are typically applied are:

- Corrections for inlet condensation effects,
- Corrections to lower heating value, of 18,400 BTU/pound, as determined from the fuel sample, and
- Final fuel specific gravity as determined from the fuel sample.

Once these corrections have been applied to either the production or the experimental test stand data, the off-line computer data reduction is initiated. This procedure generates a complete set of final results corrected to standard day conditions. These final results are printed on cards and on magnetic tapes which are then used for automatic plotting of gas generator curves, a sample of which is illustrated by Figure A-27. Once the off-line computer data reduction is complete, a permanent file of raw data, final data, and corrected results have been generated for future reference.

The experimental, detailed gas generator curves are passed on to the Compressor and Turbine Powerplant Analysis Groups where comparisons of the various component efficiencies (fan, low-pressure compressor, high-pressure compressor, high-pressure turbine, and low-pressure turbine) are made. These efficiencies were then compared to new engine levels which were derived as discussed in the following paragraphs.

Fan base-line efficiency was obtained from production engine P-686089 which ran in the Willgoos Laboratory, X-217 stand, with a production JT9D-7A(SP) fan. Data from three fan operating lines were used to predict fan performance at sea level take-off (SLTO) conditions. Although the data were taken at Willgoos Laboratory simulated altitude conditions (32,500 feet at Mach 0.8), experience has shown that Reynolds number effects are negligible for the JT9D fan.

The low-pressure compressor base-line efficiency was based on six production engine acceptance calibrations run in Middletown. These data were adjusted from standard production acceptance P_{T3} and T_{T3} instrumentation to experimental instrumentation levels.

C-2

An efficiency increment was added to the production low-pressure compressor data to account for the difference in first-stage stator configurations. The six production engines which establish the base line were built with a trunnion-mounted first-stage stator which is safety-wired at assembly to prevent movement. P-695743 incorporated a fixed first-stage stator which does not require safety wire. This configuration change results in a small performance increment which has been assessed based on data taken on experimental engine X-618-12 and production engine P-686089.

The high-pressure compressor base-line efficiency was obtained from six production engine acceptance calibrations run in Middletown. The data at stations 3.0 and 4.0 were adjusted to experimental engine instrumentation levels, and the efficiency was computed.

The high-pressure turbine base-line efficiency level is based on the accumulation of experience on 30 builds of a JT9D uncooled turbine rig.

The low-pressure turbine base-line efficiency level is based on the results of two JT9D-7 low-pressure turbine rigs run in 1974. This test rig was run with rubberized seal lands to achieve zero clearance.

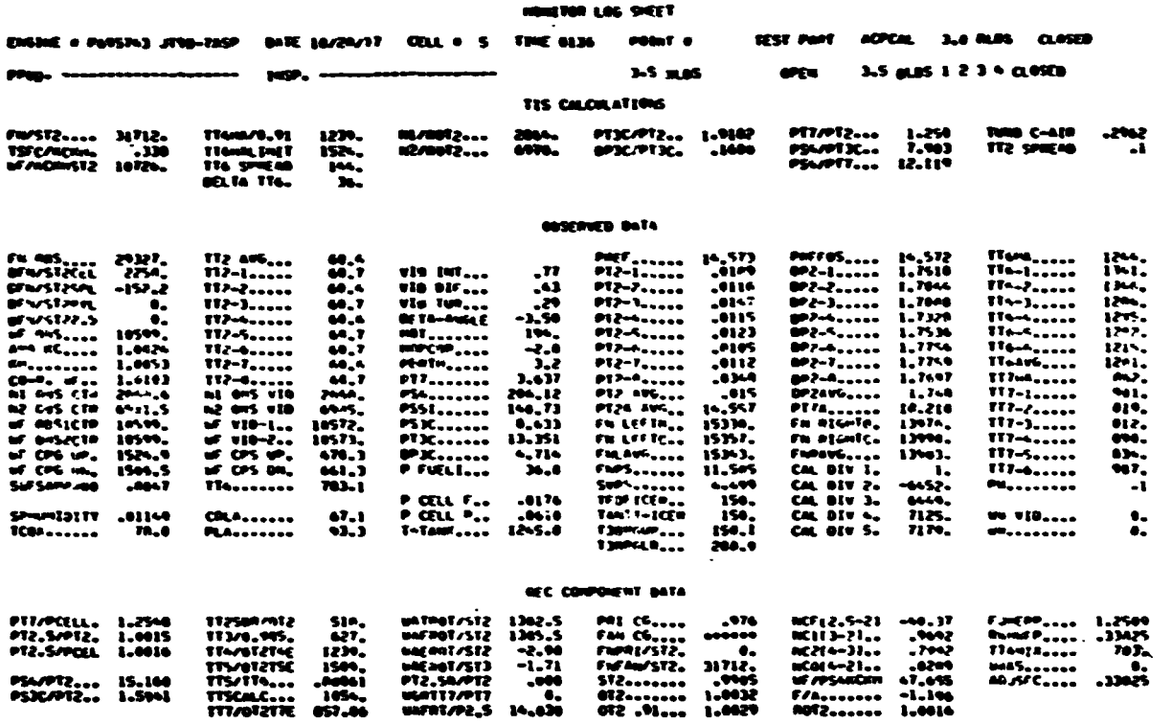


Figure A-24 *Sample Computer Printout from the APTDAC System - The system also provides a magnetic tape and/or card record for loading into the IBM 370 computer for further data reduction.*

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#-  8 STAND  ENGINE P-743-     TIME 1131  DATE 09/12/77  P&WA ENGINE TEST LOG - DATA SYSTEM CERTIFIED BY ISEP 111101

 JT9D-7A    AFTER 1080 HOURS                  BELLMOUTH TYPE  2    THUMBWHEELS  9 9 9 9 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0

FIELD NO      1          2          3          4          5          6          7          8          9          10


C#-  8 P-743-   1 JT9D-7A 091277 1856005 AFTER 1080 HOURS                    00000000
100000.809560.0000000 2    0    0    0    00100000 203000 000000 00 4000000100000000
2 C06.920 121.30 000000 000006.006.0000300000000030000008200000. 00

PARAMETER                                        BARO 2
CARD  2    0.0000     0.0000     0.0000     4114.6992   14.8160    0.0000     0.0000     0.0000     0.0000     0.0000

PARAMETER  COMPTEMP   CORRTEMP                                                 TTJ MN S                DEWPOINT
CARD  3    83.1570    82.8910    0.0000     0.0000     0.0000     0.0000     221.0500   0.0000     36.3010    0.0000

PARAMETER  AVG N1     AVG N2     A MN A                DPN MISC                                        A MN B
CARD  4    3401.0000  7459.1992  7453.7998  0.0000     0.0000     0.0000     0.0000     0.0000     7454.0996  0.0000

PARAMETER             ACOX1CPS   CON1 CPG   ACOX2CPS   CUX2 CPG
CARD  5    0.0000     857.9190   1148.7000  821.8198   1101.3999  0.0000     0.0000     0.0000     0.0000     0.0000

PARAMETER  TTI 1      TTI-2      TTI-3      TTI-4      TTI-5      TTI-6      TTI-7      TTI-8      TTI-9      TTI-10
CARD  6    66.9140    66.6670    105.1000*  66.2450    66.0620    66.1960    66.6700    66.7790    66.3320    66.1760

PARAMETER  TTI-11     TTI-12     TTI-13     TTI-14 *   TTI-15     TTI-16     TTI-17     TTI-18     TTI 19     TTI 20
CARD  7    65.9510    66.1730    67.0890    66.8500    66.2720    66.0920    66.5000    69.7540    66.8910    67.0090

PARAMETER  TTI 21     TTI 22     TTI 23     TTI 24 *
CARD  8    66.6640    66.3170    66.2980    66.8170    0.0000     0.0000     0.0000     0.0000     0.0000     0.0000

PARAMETER  TT2.6 A1   TT2.6 B2   TT2.6 B3   TT2.6 B4   TT2.6 B5   TT2.6 D1   TT2.6 D2   TT2.6 D3   TT2.6 D4   TT2.6 E5
CARD  9    147.8500   156.3700   144.7400   137.9200   130.7600   159.1800   192.1800   143.5800   139.1100   131.5200

PARAMETER  TT2.6 F1   TT2.6 F2   TT2.6 F3   TT2.6 F4   TT2.6 F5   TT2.6 H1   TT2.6 H2   TT2.6 H3   TT2.6 H4   TT2.6 H5
CARD  10   159.9100   148.0400   140.4700   136.7100   136.3600   156.3400   144.3200   141.4100   138.2600   131.6760

PARAMETER  CONF 1     CONF 2     CONF 3     CONF 4 *   CONF 5     CONF 6     CONF 13    CONF 14    CONF 9     CONF 10
CARD  14   31.8100*   32.0300*   32.1000*   32.2500*   31.8800*   32.0500*   32.0100*   31.8600*   31.8300*   31.7500*

PARAMETER             PT7 A      P BKND F   P BKND F   P BKND F   P BKND F   P BKND R   P BKND R   P BKND R   P BKND R
CARD  16   0.0000     7.0515     -1.1380    -0.9384    -0.9981    -0.9483    -1.0880    -1.0980    -1.0180    -1.0640

PARAMETER  PT3 A      PT3 A      PT3 A      PT3 A      PT3 A      PT3 C      PT3 C      PT3 C      PT3 C      PT3 C
CARD  17   17.6600    20.1450    20.2100    20.2700    20.0950    17.8000    20.1190    20.0100    20.9300    21.2250

PARAMETER  PT3 E      PT3 E      PT3 E      PT3 E      PT3 A      PT3 G      PT3 G      PT3 G      PT3 G      PT3 G
CARD  18   17.7800    20.1100    20.3800    20.9200    18.3250    17.6600    20.0000    19.7750    21.0350    18.0650

PARAMETER                                                                                PS41       PS         PS51
CARD  20   0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     281.2399   299.2399   306.9650

PARAMETER  PT4 A      PT4 A      PT4 A      PT4 C      PT4 C      PT4 C
CARD  21   311.5999   317.1199   310.8000   312.2300   317.7199   311.7999   0.0000     0.0000     0.0000     0.0000

FIELD NO      1          2          3          4          5          6          7          8          9          10
```

Figure A-25 *Sample Computer Printout from the SSDS System - The system also provides a magnetic tape and/or card record for loading into the IBM 370 computer for further data reduction.*

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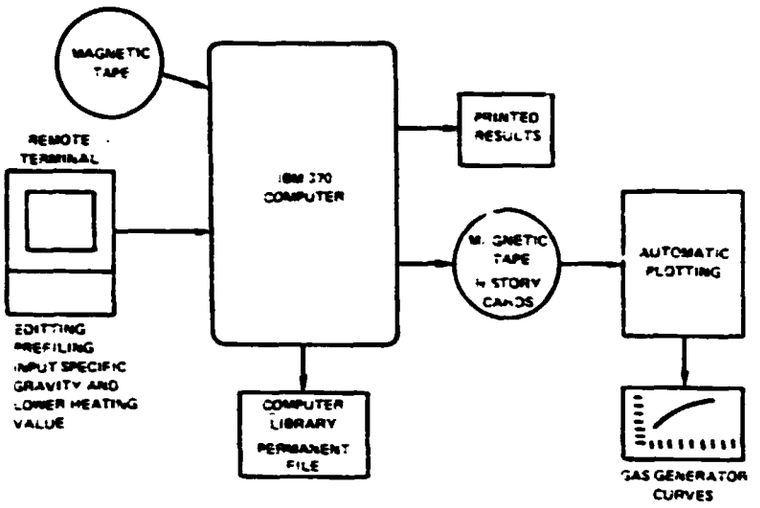


Figure A-26 *IBM 370 Computer with Peripheral Equipment - After the data are in the computer, changes or corrections to the data can be done from a remote terminal or by key punching new cards.*

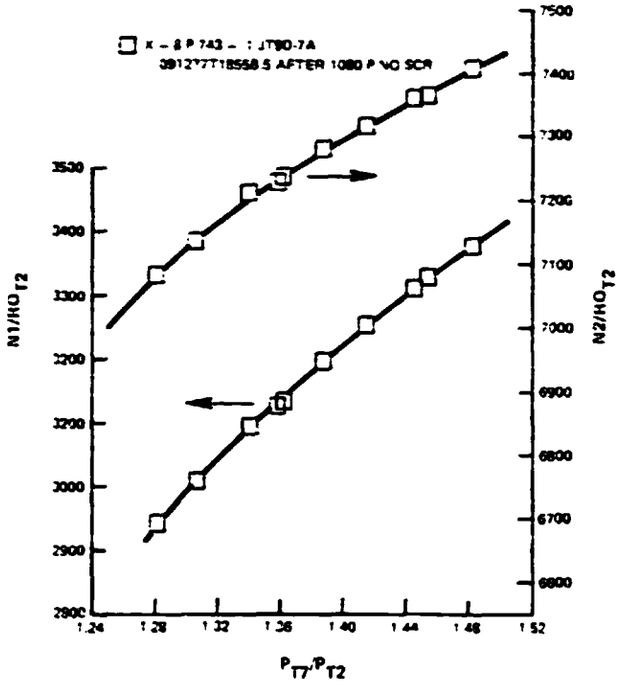


Figure A-27 *Typical Computer-Printout of Gas Generator Curve - All data, including the gas generator curves, are stored in the computer for future reference.*

APPENDIX B

TEARDOWN PROCEDURES

APPENDIX B
TEARDOWN PROCEDURES

PLANNED TEARDOWN AND INSPECTION

The Work Plan for the JT9D Engine Diagnostics Program (PWA-5504) established the measurements and inspections which were to be performed during the analytical teardown of P-695743. This work included that performed during normal engine disassembly as shown on Table B-I as well as additional measurements to be taken specifically during analytical teardowns shown on Table B-II.

These plans were modified during the disassembly process to eliminate measurement or inspection tasks which were unnecessary based on the observed condition of parts during teardown. The actual teardown procedures employed are discussed below.

ACCOMPLISHED TEARDOWN AND INSPECTION

The contractor shall perform or make provisions with participating airlines to perform, engine disassembly for normal repair or refurbishment required by standard overhaul and maintenance practices. During this disassembly procedure, the contractor shall inspect, obtain pertinent measurements (where accessible) and document deteriorated condition of accessible components/parts. The documentation of used parts conditions shall consist of the following measurements or photographs:

General

1. All measurements, observations and documented data shall be consistent with and limited to the extent of engine disassembly necessary to perform the normal repair and refurbishment tasks required by the engine condition as determined by the participating airline.
2. Where accessible, the part numbers and quantities of all gas path hardware and the supporting structure for the gas path hardware shall be recorded.
3. When measuring tip clearances take measurements every 45°, starting at TDC, and record which direction looking from.
4. Where accessible, photographs of the major gas path assemblies and typical distress to the subassemblies of the gas path components shall be recorded. As a minimum the photographs shall include:
   a. The gas path inner and outer air seals and airfoil surfaces.
   b. Individual rotor and stator vane assemblies.
   c. The combustion chamber inner and outer burner liners, and
   d. Representative distress to individual gas path components.
5. Where accessible and consistent with the extent of disassembly,* each of the fits and clearances shall be recorded.

Fan Section

1. Blade tip clearance determined by:
   a. Measuring tip clearance as assembled using Engine Manual procedures per Heavy Maintenance Manual, Section 72-31-00, Inspection/Check-02, Inspection 2008 (by shim stock with loading fixture).
   b. Calculate tip clearance by:
      (1) Measuring blade length, all blades from Z plane*
      (2) Measuring depth of rub, 12 places with vernier*

*Instructions modified or altered as required depending on the observed condition of parts.

TABLE B-I
TYPES OF DATA TO BE ACQUIRED DURING NORMAL TEARDOWNS

FAN
- Blade Tip Clearances
- Shroud Condition
- Platform Seal Condition
- Locations, Sizes, and Number of Blends on Blades
- Blade Leading Edge Condition
- Airfoil Surface Condition

LOW-PRESSURE COMPRESSOR
- First-Stage Stator Geometry
  - Leading-Edge Angle
  - Trailing-Edge Angle
  - Stagger Angle
- First-Stage Stator Fairing Condition
- Blade Tip Clearances
- Airfoil Condition Including:
  - Number and Depth of Blends
  - Leading Edge Thickness, Roughness, and Erosion
  - Surface Contamination and Roughness
- Blade Seal and Sealant Condition
- Inner Air Seal Clearance
- General Condition of Outer Air Seal
- General Condition of Third-Stage Blade Seal

HIGH-PRESSURE COMPRESSOR
- Blade Tip Clearances
- Airfoil Condition Including:
  - Number and Depth of Blends
  - Leading Edge Thickness, Roughness, and Erosion
  - Surface Contamination and Roughness
- Blade Root Sealant Condition
- Inner Air Seal Clearance
- General Condition of Outer Air Seal
- Variable Vane System Condition Including:
  - Pin Hole Wear in Unison Rings and Vane Arms
  - Pin Wear in Vane Arms
  - Bushing Wear
  - Seal Contact Between Vane and Inner Shroud

BURNER AND DIFFUSER
- General Condition of Liner Segments
  - Burning
  - Buckling
  - Cracking
  - Distortion
- Hole Sizes and Pattern for Burner Head-Section Cones
- Circumferential Hole Pattern and Hole Sizes for Louvers in Inner and Outer Liners
- Dimensions of Primary Combustion Holes and Secondary Slots in Inner and Outer Liners

***FIRST-STAGE TURBINE* VANES AND SUPPORTING STRUCTURE**
- Airflow Check for Each Vane
- Class Check for Each Vane
- Extent of Burning, Distortion, and Cracking of Each Vane
- *Rearward Deflection of First-Stage Vane Inner Support*

HIGH-PRESSURE TURBINE
- First- and Second-Stage Rotor Imbalance
- Airflow Check for:
  - First-Stage Baffles and Blade Sets
  - Second-Stage Vanes
  - Second-Stage Blades
- Class Check for Second-Stage Vanes
- Extent of Burning, Distortion, and Cracking of Each Airfoil
- Second-Stage Blade Root Sealant Wear
- Second-Stage Blade Twist
- Location, Axial Length, and Depth of Rubbing on Each Seal Land Surface
- Number 3 Bearing Compartment Sealing System

LOW-PRESSURE TURBINE
- Rotor Imbalance for:
  - Complete Assembly
  - Each Rotor Assembly
- Class Check for Each Vane
- Extent of Burning, Distortion, Cracking, and Sulfidation of Each Airfoil
- Root Sealant Wear of Each Blade
- Twist for Each Blade
- Location, Axial Length, and Depth of Rubbing on Each Seal Land Surface

- Number 4 Bearing Compartment Sealing System
- Distortion and Damage to Exhaust Case Struts
- Condition of Tailpipe Throat

COMPONENT AND ACCESSORIES
- Tangential on-Board Injection System
  - Airflow
  - Nozzle Erosion
  - Tongue-In-Groove Seal Wear
- Fuel Nozzle Flow and Spray Angle
- Water Ingestion System External Leakage
- General Condition of Thrust Frame and Related Components

NOTE: Actual data obtained will be limited by the accessability of components and parts during disassembly. No parts will be disassembled solely to permit acquisition of inspection data for the proposed program

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TABLE B-II
TYPES OF ADDITIONAL DATA TO BE ACQUIRED DURING ANALYTICAL TEARDOWNS

FAN
- Cross Shroud Dimension, Each Blade
- Blade Airfoil Surface Condition Photograph 2 Blades

LOW-PRESSURE COMPRESSOR
- Blades and Vanes (3 Stages):
  - Surface Finish for 2 Airfoils in Each Stage
- Indexing of Fourth-Stage Stator Vanes Relative to Downstream Intermediate Case Struts

HIGH-PRESSURE COMPRESSOR
- Surface Finish for 2 Airfoils in Each Stage
- Erosion of Vanes and Blades in All Stages
- Variable Vane System Including:
  - Max. and Min. Tangent Angles (Vane Load Reversed) of Each Vane
  - Pin Diameters
  - Unison Ring Pin Hole Diameters
  - Vane Arm Pin Hole Diameters
  - Inner Trunion Diameters
  - Unison Ring Runner-to-Case Clearance
- Inner Shroud Axial Deflections Stages 5 through 7
- Cold Flow Leakage at Blade Roots Stages 5 through 15

HIGH-PRESSURE TURBINE
- First and Second Stages:
  - Throat (Exit) Area of Stator Vane Assemblies at Each Radial Design Station
  - Throat (Exit) Area of As-Removed Rotor Assemblies at each Radial Design Station
- Shadowgraph 5% of Vanes and Blades at 3 Radial Design Stations
- Flow Test of First-Stage Rotor Assembly
- Flow Test of Root Attachment Regions of Second-Stage Rotor

LOW-PRESSURE TURBINE
- Third, Fourth, Fifth, and Sixth Stages:
  - Throat (Exit) Areas of As-Installed Vane Assemblies at Each Radial Design Station
  - Shadowgraph 5% of Vanes and at 3 Radial Design Stations
- Shadowgraph and Tangent Angle of Each Exhaust Case Strut at Each Radial Design Station

2. Fan Blade
   a. Document shroud condition by visual inspection for shingling, wear, erosion and area of contact of adjacent blades on shroud face. Reference Engine Manual, Section 72-31-05, Visual Inspection, Page 310, 312, 317. Photograph or sketch worst case condition and typical shroud.
   b. Inspect for and (document condition) of seals on platform, quantity missing, loose, torn. See Section 72-31-05, Inspection-00. Photograph worst case conditon.
   c. Inspect for and (document) number of blends per blade, radial location

from platform, width and depth. Sketch or tabulate results. Photograph worst case condition.

d. Visually inspect and document condition of leading edge of blades for erosion, roughness and thickness, and

e. Visually inspect and document airfoil roughness and contamination.

f. Measure and record inner and outer cross shroud dimensions of one blade. Reference P/N 778601.

g. Document surface condition of leading edge of blades such as erosion, roughness and thickness. Photograph two typical blades.

h. Perform special measurements per Attachment B-1.

3. Fan Exit Guide Vane

a. Document quantity of blends and average depth of blends.

b. Document surface roughness and leading edge shape of one bottom fan exit guide vane.*

Low Pressure Compressor

1. First Stator

a. Measure and document tangent angle (N) of all vanes of a trunnion stator. See Overhaul Manual, Section 72-32-06, Subassembly-00, Figure 502. Omit for fixed stator.

b. Measure and document A and H angles of 50 percent vanes in two sections, per Attachment B-2 (omit for fixed stator).

c. Document results of overall visual inspection.

*Instructions modified or altered as required depending on the observed condition of parts.

2. Blade Tip Clearance

a. Measuring tip clearance as assembled using Engine Manual procedure. Heavy Maintenance Manual, Section 72-32-00, Inspection/Check-02, Index 36, 37, 43. Measure second and fourth stage assembled, third stage during disassembly – with shim stock.

b. Calculating tip clearance by measuring:

(1) Depth of rub in outer air seals, eight places each stage, at deepest part of rub indication.

3. Blades and Vanes (Three Stages) – Full deblade not required. Deblade selected area as requested by Engineering.*

a. (Document) number of and average depth of FOD/BMOD or blends, on each stage, per visual inspection, Heavy Maintenance Manual, Section 72-32-05, Inspection/Check-00. Photograph typical and worst case damage and blends.

b. By visual inspection (document) condition of seals and root sealant.

c. Visually inspect and (document) condition of leading edges of all blades for roughness, erosion and thickness.*

d. Visually inspect and (document) airfoil surface contamination and roughness.

e. Perform special measurements per Attachment B-1.

4. Inner and Outer Air Seals

a. Calculate inner air seal clearances by measuring, recording:

(1) Diameter of knife-edges, by tape or vernier.

(2) Diameter of seal lands, by tape.

(3) Depth of groove in seal lands, eight places each land.

b. Visually inspect and (document) condition of outer air seals. Photograph damaged areas, wear patterns.

5. Visually inspect and document condition of 3.0 bleed seal.

High Pressure Compressor (11 Stages)

1. Blade tip clearances determined by:

a. Measuring tip clearance as assembled using Engine Manual procedures. Check clearance eight places each stage with shims.

b. Calculating tip clearance by measuring:

(1) Blade length, on blades designated by Engineering inspection.*

(2) Depth of rub in outer air seal, eight places.

(3) Visually inspect and (document) condition of outer air seals. Photograph worst case and typical wear condition.

2. Blades and Vanes (11 Stages) – Full deblade not required. Deblade selected areas as requested by Engineering.

a. (Document) number of and average depth of FOD in each stage, blades and vanes. Photograph typical damage and worst case.

b. Document condition of blade root and case flange sealant each stage.

c. Visually inspect and (document) condition of leading edge of airfoils for erosion, roughness and thickness. Measure thickness of airfoil sample from each stage.*

d. Measure and document erosion per Engine Manual.*

e. Evaluate torque on stator case and flange bolts. (Loose, finger tight, tight)

f. During initial disassembly, document bolt torque in tightening direction of every fourth bolt at J, K, M, N flanges. If bolts are found loose, then do each bolt.

g. Perform special measurements per Attachment B-1.

3. Inner Air Seal Clearances

a. Calculate inner air seal clearances by measuring:

(1) Diameters of knife-edges, by vernier.

(2) Diameters of seal lands by tape in unrubbed portion of seal lands.

(3) Depth of groove in seal land, eight places.

4. Variable vane system (inlet guide vanes through seventh stage).

a. Measure vane arm angles per Attachment B-3.

b. Install rigging pins in inlet guide vane through seventh stage and measure tangent angle of ten selected vanes (each stage). See Attachment B-4.*

c. Pinhole wear in unision rings and vane arms. Inspect by eye and measure anything obviously out of limits.*

*Instructions modified or altered as required depending on the observed condition of parts.

d. Bushing wear – visual inspection by Engineering. Sample measure selected bushings.*

e. Vane to inner shroud set contact. Inspect visually for evidence of contact.

f. Measure and document inner shroud axial deflection on stages five and seven per the Engine Manual.

g. Measure and document unison ring runner to case clearance. Prior to disassembly, unloaded per manual procedure.

h. Measure and document unison ring runner thickness and clearance per Attachment B-5.*

Burner/Diffuser Module

1. Inner and Outer Burner Liners*

   a. Visually inspect and (record) the degree of burning, buckling, distortion and cracking of the liner segments.

   b. (Document) false head burning, cracking, gap dimension.

   c. Measure and record cone alignment, T&G fit, rear fit. Tape outer liner diameter forward of the first louver (1¼ inch down stream from Plane A).*

2. First Stage Turbine Vane and Supporting Structure

   a. Airflow check each of 66 first vanes in the as-removed condition.

   b. Class check each of 66 first vanes in the as-removed condition, by gage.

   c. Visually inspect and (record) for each vane the extent of burning, distortion and cracking.

   d. Inspect the first vane inner support for rearward deflection. Measure and record the gap between the rear inner support feet where the first vanes fit in. Measure at eight circumferential locations. See Attachment B-6.

   e. Measure outer burner case snap fit at M flange.

3. TOBI Duct and Inner Burner Case*

   a. Airflow check TOBI duct in as-removed condition.

   b. Inspect and (document) degree of TOBI duct nozzle erosion and TOBI duct tongue-in-groove seal wear. Measure TOBI tongue and groove dimension.

4. Accessories and Components

   a. Perform as-removed flow and spray angle check of fuel nozzle and support assemblies.

   b. Inspect the thrust frame and components per Overhaul Manual.

High Pressure Turbine Module

1. Determine the throat (exit) area of the as-installed first and second vane assemblies and of the as-removed first and second turbine rotor assemblies. Measurements to be made at each vane or blade Engineering Materials Drawing section and the area calculated by Simpson's rule.

2. Perform a flow test of the second stage rotor assembly root attachment area. Send bladed rotor to Middletown, Building 340, Department 4951, care of Carl Currie.

3. Visually inspect and (record) for each vane and blade the degree of burning, distortion, cracking, erosion and/or sulfida-

*Instructions modified or altered as required depending on the observed condition of parts.

tion. Photograph worst case condition and typical condition.

4. Airflow check in the as-removed condition each of 116 first stage baffle and blade sets, 90 second vanes and 138 second blades. Cross index airflow data to blade S/N, and for vanes, position in the engine.
5. Class check in the as-removed condition each of 90 second vanes by gage.
6. Inspect and (document) the rub location and axial length and depth for each seal land surface. Inspection to include the No. 3 bearing compartment sealing system (all No. 3 compartment seals).
   a. Measure and record all knife-edge to seal land clearances.
7. Inspect and document the degree of second blade root sealant wear. Note conditions of chipping, loose material, burnishing.
8. Inspect ten percent sample second stage blades for twist per Engine Manual.*
9. Measure diameter of first rotor leading edge, midchord, and trailing edge by tape.
10. Measure diameter of first outer air seal segments, front and rear, in nonrubbed area (by tape).
11. Measure second rotor knife-edge diameter by tape.
12. Measure second outer air seal diameter in ungrooved area.
13. Measure second inner support deflection per Engine Manual Index 1578.
14. Measure M flange diameter in eight places by vernier.
15. Measure and record second vane axial spacing per Attachment B-7 (15 random vanes), and second inner support mating surfaces.

Low Pressure Turbine Module

1. Determine the throat (exit) area of the as-installed third vane assemblies. Measurements to be made at each vane or blade Engineering Materials Drawing section and the area calculated by Simpson's rule.
2. Visually inspect and record for each vane and blade the degree of burning, bow, cracking and/or sulfidation.
3. Inspect and document the rub location and axial length and depth for each seal land surface, eight places each.
4. Visually inspect and (document) FOD damage to the turbine exhaust case struts.
5. Inspect the tail pipe throat area (QEC primary nozzle area).
6. Tape knife-edge diameters of all rotor and seals and all seal lands Measure seal lands on unrubbed surface.
7. Measure and document runouts on No. 4 bearing housing by inspecting concentricity of "P" flange snap on TEC with respect to inner diaphragm flange snap.

*Instructions modified or altered as required depending on the observed condition of parts.

ATTACHMENT B-1

INSPECTION

Re: Special Measurements on Engine P-695743

FAN BLADES

Serial No. 12 and 19 - Length measuring gage (special gage) per Overhaul Manual + Dimension No. 6 per special check.

Serial No. 12 - Surface roughness checks at 18 places marked on blade.

LOW-PRESSURE COMPRESSOR

Third Stage Blades - one piece selected by Engineering:

Blade length per Overhaul Manual

Surface roughness checks, 18 places *(0.10 - 0.20 inch from platform at midspan; 0.10 - 0.20 inch from tip at leading edge, trailing edge, and midchord on both concave and convex surfaces).

HIGH-PRESSURE COMPRESSOR

Fifth-stage blade	- one piece	Same measurements as for the third-stage low-pressure compressor above.
Ninth-stage blade	- one piece	
12th-stage blade	- two pieces	
13th-stage blade	- one piece	
14th-stage blade	- one piece	
15th-stage blade	- one piece	

Fifth- and sixth-stage variable stators; inspect stators marked on shroud for ease of opening and closing by moderate finger pressure per Teardown and Inspection Instructions.

Sixth-stage stator vanes - two pieces marked on airfoil ID trailing edge. Remove from assembly and measure surface roughness at 18 places same as for third-stage low-pressure compressor blades above. Inspect ID bushings and trunions for wear.

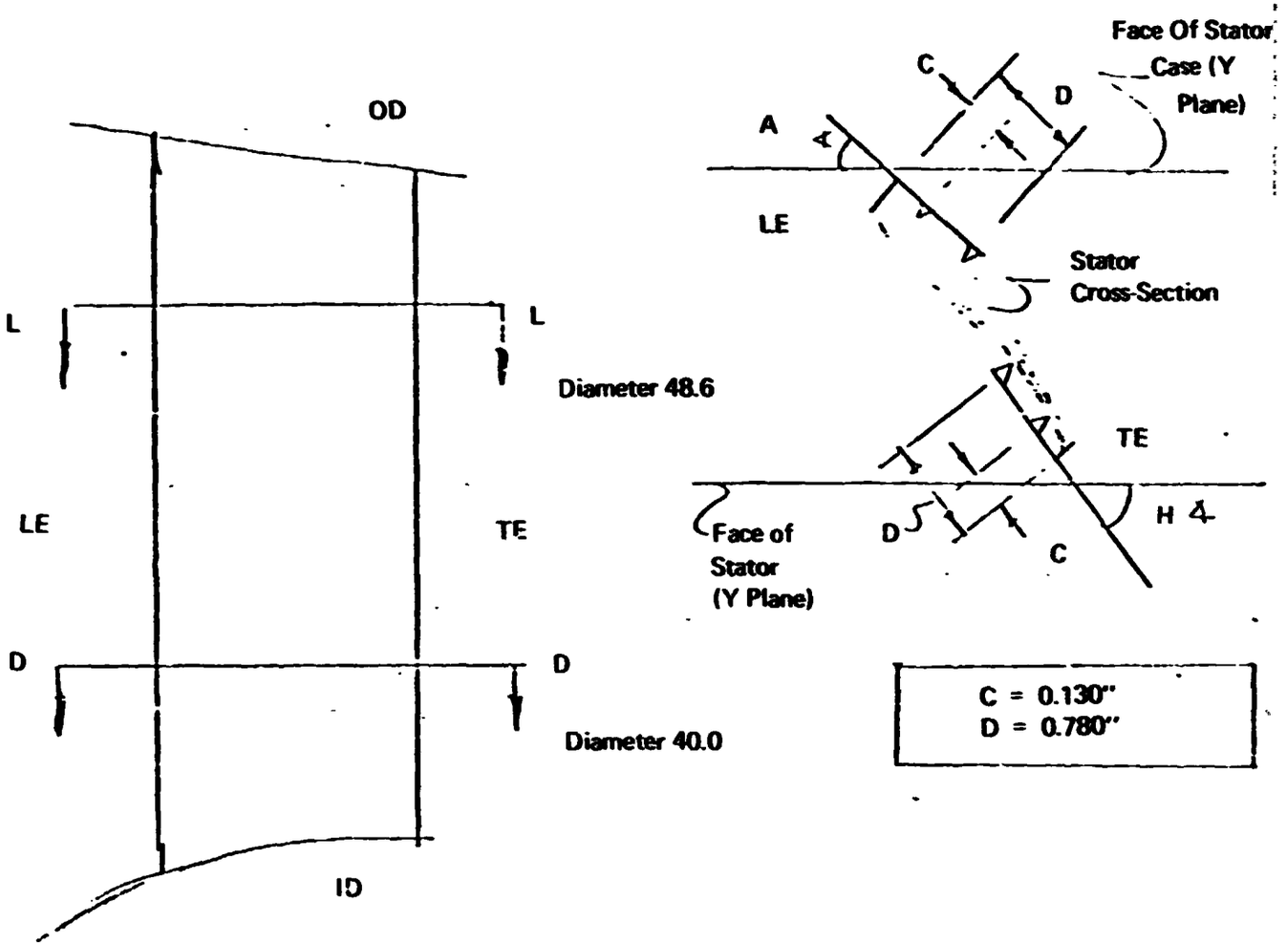
Roland Bouchard

*Approximate location gaged by eye is acceptable.

ATTACHMENT B-2

Stator 1 "A" and "H" Angle Measurements

50% Stator 1 vanes in the assembly should have their "A" and "H" angles measured at the given sections as shown.



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ATTACHMENT B-3

(1) Following is variable stator linkage - adjustment/test

(2) Procedure for 6 valve arms for variable accessory.

(a) Rotate variable stator system (crow foot wrench may be used) to the six degrees rigging position and insert PWA 25637 rigging pin at the compressor stator lever.

(b) With the lever pinned at the plus six degrees rigging position, measure vane arm Angle A (see Figure 503) on the IGV, 5th, 6th and 7th stage using PWA 28199 Gage and a suitable standard vernier protractor.

1 Release tabwasher on bolt securing vane arm assembly. Remove bolt and retain, discard tabwasher.

2 Install detail-2 (pilot bolt) in place of bolt.

3 Position detail-1 (body) over detail-2 picking up vane arm pin. Secure with thumbscrew, (detail-3).

4 Loosen nut from mating case flange, position detail-4 (plate) and secure.

5 Place base of vernier protractor on detail-4 (plate), adjust protractor arm to detail-1 (body)

6 Read angle on protractor, record angle.

7 Remove PWA 28199 Gage

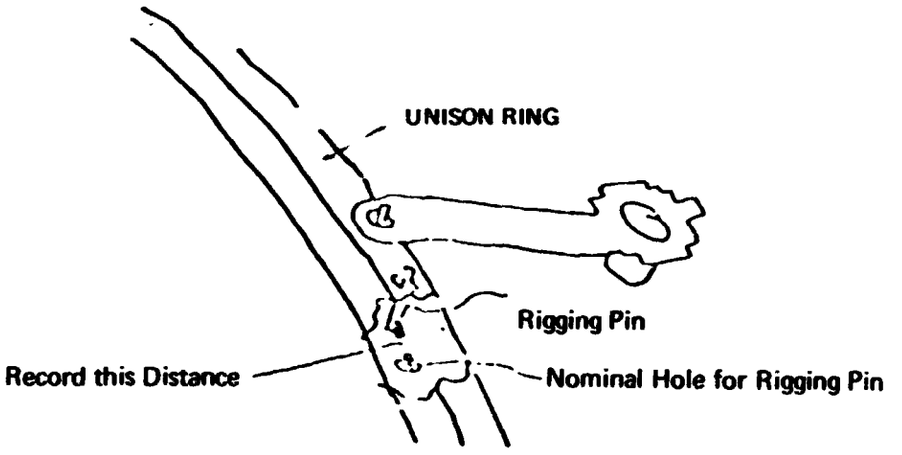
a Remove detail-4 (plate), retorque nut at mating case flange.

b Remove detail-3, -1, and -2.

8 Using new tabwasher install bolt removed in step 1. Torque bolt.

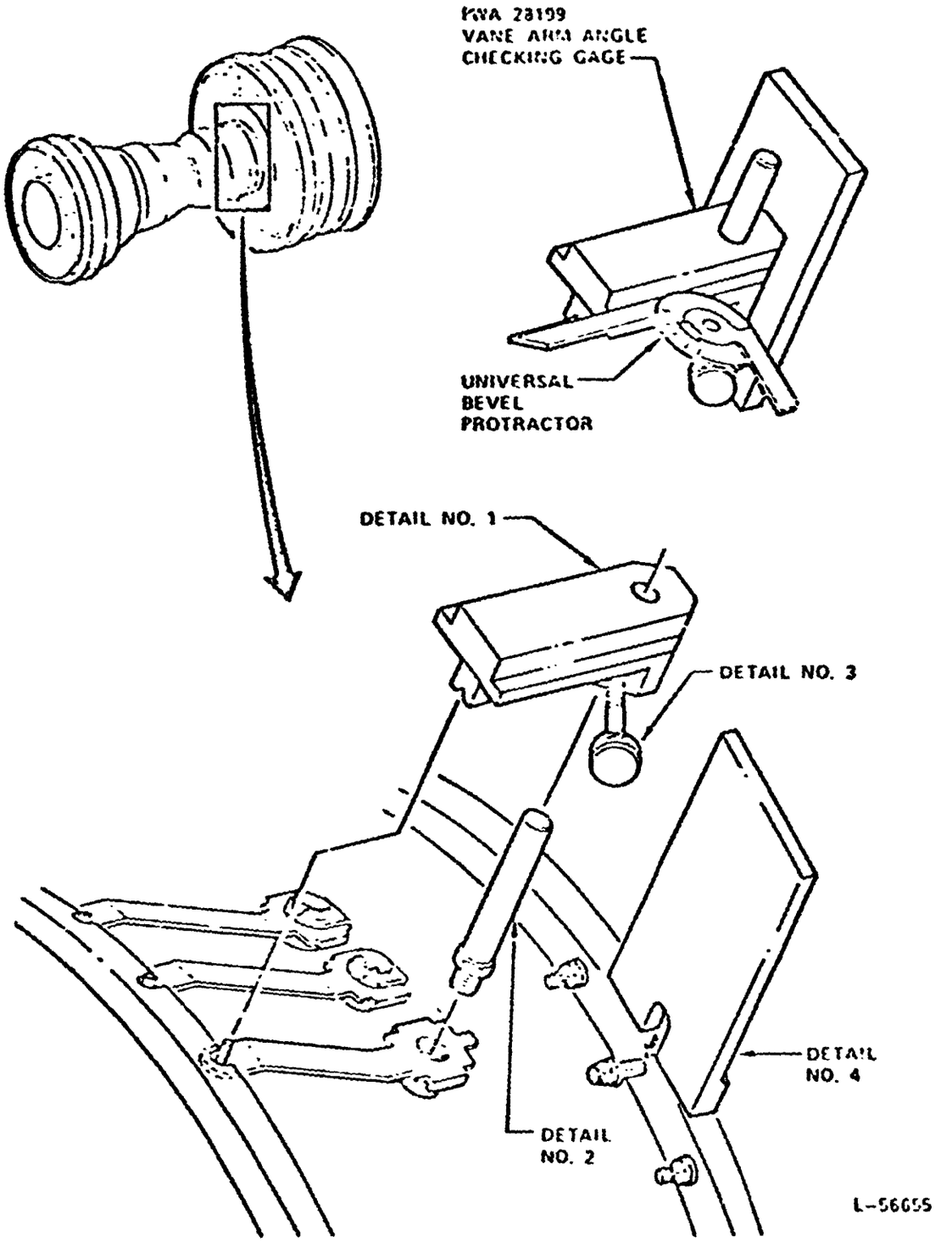
(c) With lever remaining pinned at the plus six degrees rigging position, insert rigging pins at the synchronizing rings. If rigging pins cannbe inserted*

*Make a note of any rigging pin that cannot be inserted, and record the magnitude of the tangential offset (see sketch below).



ATTACHMENT B-3 (Cont'd.)

VARIABLE STATOR LINKAGE - ADJUSTMENT/TEST



Variable Stator Vane
Arm Angle Measurements
Figure 503

ATTACHMENT B-4

Additional Variable Vane Testing

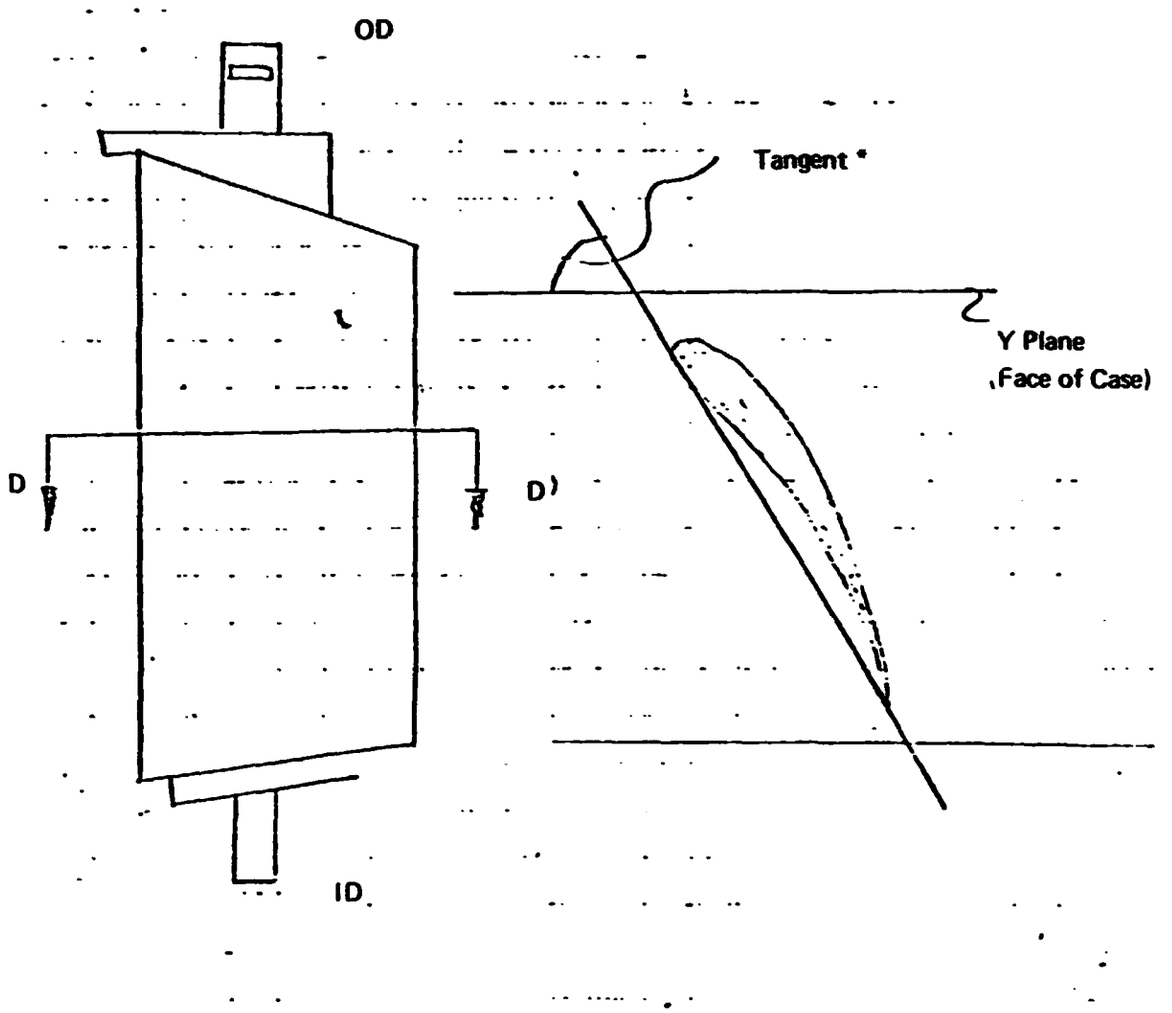
After module disassembly the following measurements should be taken on 10 vanes per stator assembly.

1. Insert rigging pin into 6 degree rigging hole on unison ring.

2. Measure tangent angles on variable vanes as shown below:

Vane	Section	Diameter
IGV	D-D	32.599"
S5	D-D	30.852"
S6	D-D	30.344"
S7	D-D	28.692"

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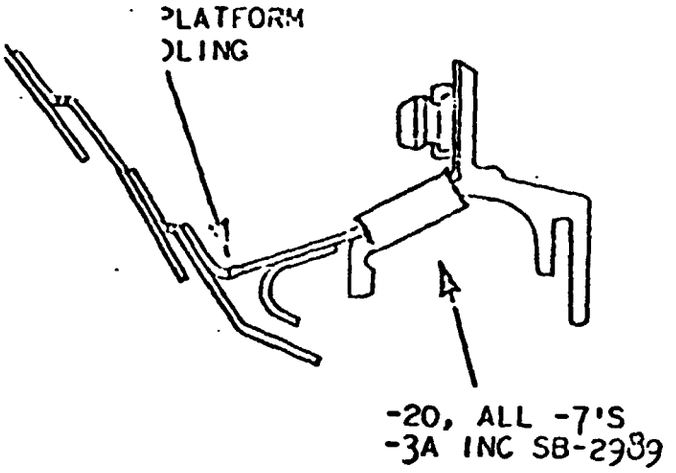
ATTACHMENT B-5

HPC RUNNER CLEARANCE/THICKNESS

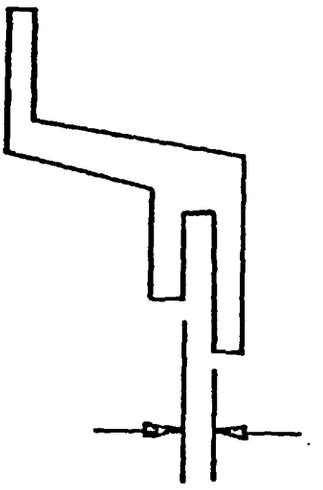
1. Measure clearance – start at rig pin location. Continue in a clockwise direction as viewed from the rear.

	IGV		5TH		6TH		7TH		COMMENTS
	CL	THK	CL	THK	CL	THK	CL	THK	
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13					–	–			
14					–	–	–	–	
15	–	–			–	–	–	–	
16	–	–			–	–	–	–	

ATTACHMENT B-6

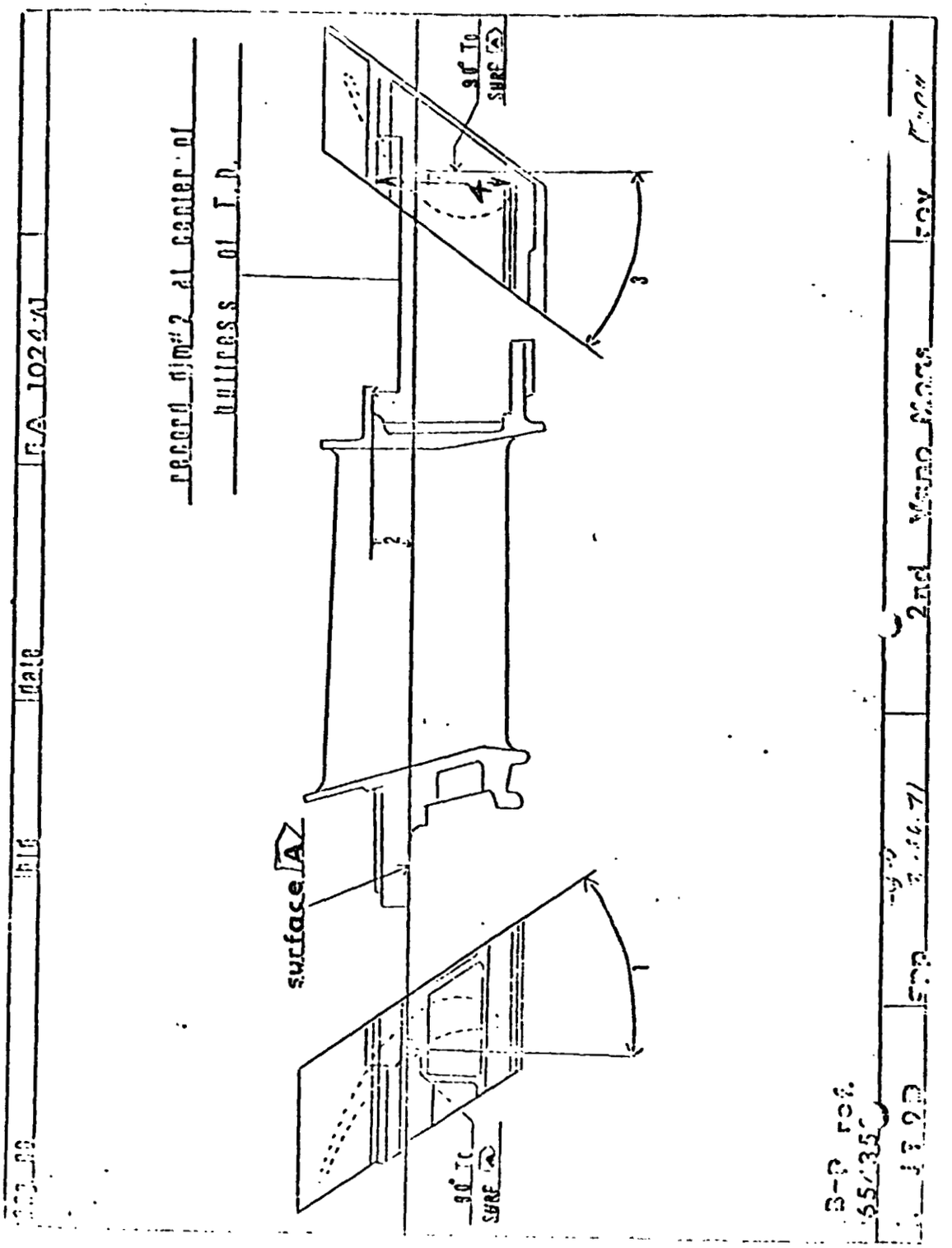


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MEASURE AND RECORD THE GAP BETWEEN THE REAR INNER SUPPORT WHERE IT MATES WITH THE FIRST T VANES', TAKE MEASUREMENTS IN 8 CIRCUMFERENTIAL LOCATIONS.

ATTACHMENT B-7



APPENDIX C

QUALITY ASSURANCE REPORT

APPENDIX C

QUALITY ASSURANCE REPORT

INTRODUCTION

The Quality System provides for the establishment of quality requirements and determination of compliance from procurement of raw material until the end-item article is accepted. The System ensures the detection of nonconformances, their proper disposition, and effective corrective action.

Materials, parts and assemblies are controlled and inspected to the requirements of the particular engineering program involved. A full production-type program requires inspection to the requirements indicated on the drawings and pertinent specifications. On experimental programs Engineering may delete or waive noncritical inspection requirements. However, all parts on certain engine test programs and critical parts on other programs require complete inspection. Details are provided in Experimental Quality Assurance procedures.

Parts, assemblies, components and end-item articles are inspected and tested prior to delivery to ensure compliance to all established requirements and specifications.

The results of required inspections and tests are documented as evidence of quality. Such documents, when requested, are made available to designated Government Representatives for on-site review.

Standard P&WA CPD Quality Assurance Standards currently in effect were followed during the execution of this sub task. Specific standards were applied under the contract in the following areas:

1. Service Center Assembly
2. Production Test
3. Experimental Assembly
4. Experimental Test
5. Instrumentation and Equipment
6. Purchased Parts
7. Data

All Parts used were Final Inspected Parts from normal sources and were properly identified by the required markings.

SERVICE CENTER ASSEMBLY

In the Service Center Assembly area the engine was:

1. prepared for the initial tests
2. disassembled and reassembled with experimental cases
3. analytically torn down
4. rebuilt for service

The Service Center's operating procedures & practices are approved by the FAA and controlled under the FAA Certification Station No. 3990 (Class III). Example of the types of documents utilized at that Station are shown in Attachments C-1, C-2, and C-3. In all cases, the work is signed off, dated, and approved.

PRODUCTION TEST

In the Production Test facilities the engine was:

1. calibrated as required to document the overall engine performance deterioration since new

2. calibrated for "final acceptance" prior to return to service.

The operating procedures and practices followed in those facilities were monitored by Test Quality Assurance Inspectors, under FAA Station No. 3990, which insured conformance to established P&WA specifications and procedures.

EXPERIMENTAL ASSEMBLY

In Experimental Assembly, the engine was received fully assembled for installation and removal of the additional performance measurement probes. The work was performed in D-955 under the Experimental Construction Procedure, Volume 9, Procedures. Attachment C-4 is a sample document out of Volume 9 which established procedures for internal audits. Volume 9 establishes the procedures and responsibilities for the control of the various quality standards within the Department. Attachment C-5, PWA Form 64, is a sample of the types of documents utilized for specific instructions to the Experimental Assembly floor.

EXPERIMENTAL TEST

In Experimental Test, D-956, the engine ran a performance calibration. The testing was performed under Experimental Test Department Procedures No. 8 which covers testing in X-8 stand. Attachment C-6, No. 8.3, is a sample document out of Test Procedures No. 8 which specifies the Pre-Start Procedures for X-8 Stand.

INSTRUMENTATION AND EQUIPMENT

Instrumentation and equipment are controlled under the P&WA Quality Assurance Plan.

The accuracy of gages and equipment used for quality inspection functions is maintained by means of the control and calibration system described in Gage Standards Procedures. The system provides for the maintenance of reference standards, procedures, records, and environmental control when necessary.

Reference standards are maintained by periodic reviews for accuracy, stability, and range. Certificates of Traceability establish the relationship of the reference standard to standards in the National Bureau of Standards (NBS).

Recertification is accomplished by recalibration at NBS or at a laboratory with proven traceability. When reference standards are used to calibrate work standards, calibration is accomplished in environment-controlled areas.

Initial calibration intervals for gaging and measuring equipment are established on the basis of expected usage and operating conditions. The computerized gage control system provides a weekly listing of all gages and equipment requiring calibration, highlighting overdue items.

Gages and tools used to measure final dimensions are calibrated by Gage Standards.

PURCHASED PARTS

Pratt & Whitney Aircraft has the responsibility for the quality of supplier and supplier-subcontractor articles, and effects its responsibility by requiring either control at source by P&WA Vendor Quality Control or inspection after receipt at P&WA. Records of in-

spections and tests performed at source are maintained by the supplier as specified in P&WA Purchase Order requirements.

A Quality Assurance Representative is assigned by P&WA to a supplier's facility when it is more economical or effective to control quality in this manner. The Representative ensures that the supplier includes P&WA quality requirements in subcontracts. He is responsible for surveillance of the supplier and the supplier's subcontractors and ensures that the supplier takes prompt corrective action when necessary.

Quality Assurance makes certain that required inspections and tests of purchased materials and parts are completed either at the supplier's plant or upon receipt at P&WA.

Receiving inspection includes a check for damage in transit, identification of parts against shipping and receiving documents, drawing and specification requirements, and a check for Materials Control Laboratory release. Positive identification and control of parts is maintained pending final inspection and test results.

Control of vendor calibration procedures is accomplished through stipulation of calibration requirements on the P&WA Purchase Order and surveillance by Vendor Quality Control personnel.

DATA

The performance data for P-695743 in the Production test stand were recorded on the Automatic Production Test Acquisition & Control System (APTAC), which was calibrated to specific P&WA procedures prior to the specific tests. The calibration of the various measurement systems use standards which are traceable to the NBS. The calibration of these various sensory devices are relayed to the computer which fits the best straight line through each point for use during engine test.

The performance data for P-695743 in the Experimental test stand were recorded on the Steady State Data System (SSDS), certified per Instrumentation Standards & Procedures (IS&P) No. 3:3101 shown in Attachment C-7. These procedures specify the calibration intervals for the various components requiring laboratory certification. During each data acquisition, the systems record certified reference parameters to provide an "on-line" verification that the systems are performing properly. An instrumentation certification is shown in Attachment C-8.

These "confidence" data are reviewed at the time of the run and are later analyzed to provide an overall assessment of the systems operations.

Quality Assurance personnel ensure that records pertaining to quality requirement are adequate and maintained as directed in Experimental Quality Assurance Procedure.

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PRATT & WHITNEY AIRCRAFT
SERVICE CENTER

ENGINE NO.: 695743 JOB NO.: DD-701058

MOD.: JT9D-7A DATE: 7-25-77

CUSTOMER: NASA (Pan Am)

RECEIVE-IN REPORT

JT9D

NOMENCLATURE		NOMENCLATURE	
cords Received:	Yes ___ No ✓	Frt Compr F.O.D. Check	Vis ok
Engine Covers -	Front Rec'd Fan Rear Rec'd Exhaust Rec'd	Oil Tank Vis ok Dipstick N/Rec'd CDX Unit Yes ___ Class #4, 5 Received No ✓	
Main Oil Strainer	Non cleanable Strainer Rec'd Vis ok	Turbine F.O.D. Ck.	Vis ok
Centrifugal Strainer	Vis ok	External Tubing	QEC, N/D. Vis ok where pos.
Last Chance Strainer	Vis ok	Filter Assy.	Vis ok
Oil Sample	Not Required	Record White Rubber Condition Stages	
Splitters Rec'd 270 ___ 360 ___ None ✓		see below 2 wear 3 wear 4 wear	
N2 Speed Plate 6931	RPX 85.78%	Lo Turb. Data Plate S/N	D-95743
EVC Linkage Fuel Control Linkage	QEC, Rec'd N/D	Hi Turb. Data Plate S/N	C-95743
		Hi Compr. Data Plate S/N	B-95743
Accy. Dr. Covers	(1) Cover Rec'd Remaining Recds QEC, Rec'd. N/D	Main G/Box Data Plate S/N	F-95743
Nose Cone & Cover	N/D to Eng Vis ok Rubber ok	Angle G/Box Data Plate S/N	QEC N/D N/N

Remarks: Engs Rec'd with QEC, less Nose Cowl - CDX unit N/Rec'd
Eng Plate Stamped Cl. 5 Req'd. - Light to moderate Rub wear in
F.D. frt fan Case - For Blade Tied (1) area to Prevent windmilling.
1) Broken Stud on H.T. Junction Box (AX) Various frt fan Blade Tips
have a discoloration from Rubbing. - Light to moderate
Rub wear in LPC outer rub strips. LPT balance cases Loose
AS Rec'd. - Light sheared cable attaching to Remote plug. Temp. repaired

Borescope & Inbearings inspection - Vis ok clear gas Path. 7-26-77

Partial Cowls 7-26-77 7/24/77 7/24/77
Co. 7-25-77 Insp. W Tucker L/M B Hanaway F/M QBL Date 7-26-77

Form Approved by: Date: 7-11-77

(40)

ENG: 695743 2nd T/D MODEL JT 7-7A SP

W-B NO. DD 701058 PAGE Pg 3 of

DISASSEMBLY STEPS	DISASSEMBLY INSTRUCTIONS	BY
	TAKE PHOTOS OF MAJOR GAS PATH ASSEMBLIES AND TYPICAL DISTRESS AREAS - PHOTOS SHALL INCLUDE:	
	A. GAS PATH INNER & OUTER AIRSEALS & AIRFOIL SURFACES.	
	B. INDIVIDUAL ROTOR & STATOR VANE ASSEMBLIES.	
	C. COMB. CHAMBER INNER & OUTER, BURNER LINERS.	
	D. REPRESENTIVE DISTRESS TO INDIVIDUAL GAS PATH COMPONENTS.	
	INSPECT TAIL PIPE THROAT AREA - RECORD - DONE PER DEC 1969	
	DO BLUE MAX CHECK.	
(A)	INSTALL RIGEING PINS AT INLET GUIDE VANE THRU 7TH STG AND MEASURE TANGENT ANGLE OF (10) VANES PER STAGE. LOAD VANE IN EACH DIRECTION TO OBTAIN MIN. & MAX. - RECORD	
(B)	MEASURE VANE ARM ANGLES PER ATTACHMENT "B" PRIOR TO ROTOR DISASSY. ("A" TO BE DONE AFTER ROTOR DISASSY)	
	FAN: FAN BLADES. DOCUMENT CONDITION OF SEALS ON PLATFORM - QTY MISSING NICK LOOSE NICK TORN NICK	
	REMOVE FAN & DEBLADE POSITION MARK BLADES	
	MEASURE FRT. FAN CASE RUBSTRIP I.D. FRT & REAR ON ENGINE & CHART RUB.	
	111735 Y/N.	
	REMOVE L.P.C. & REMOVE 1ST STATOR (See Pg 4)	
	MEASURE I.D.C. BLADE TIP CL. AND MTH	

Pratt & Whitney

SERVICE CENTER
ENGINE INSPECTION RECORD

JT9D-7
& 7A, 7F

RECORD OF MEASUREMENTS – FITS AND CLEARANC

ENGINE 695743 JOB NO. DD-701050 CUSTOMER P.S.E. (N.A.S.A. - P.A.)

PAGE 1 of

REF. NO.	O.I.R.	DESCRIPTION (IPC MODULE)		OHM DIM Min.	OHM DIM Max.	OHM LIMITS Min.	OHM LIMITS Max.	OHM LIMITS Repl. If Over	ACTUAL DIM.	ACTUAL FIT OR CLEAR.	BX INSP	W O NO
310	A	5th Stg. Air Seal (Frt.)	OD	23.509	23.519	.036	.056	.101	23.571	047		
		Shroud - 5th Stg. Compr. Case (Frt.)	ID	23.555	23.565				23.561			
311	A	5th Stg. Air Seal (Intermed.)	OD	23.609	23.619	.036	.056	.101	23.609	057		
		Shroud - 5th Stg. Compr. Case	ID	23.665	23.665				23.66			
343	B	5th Stg. Vane	OD	.4365	.4370	(See 72-35-06, INSP.)						
		Stator Brg.	ID	.4380	.4395	.001	.004	.004				
344	A	Stator Brg. by Selection	OD			.000	.001T	*.002T				
		Compr. Case	ID	.6530	.6560							
348	A	Compressor Unison Ring Pin	OD	.1560	.1565	.0002	.0027	.0027@				
						.0002	.0027	.0128				
		Unison Ring	ID	.1567	.1587							
349	A	Compr. Unison Ring Pin	OD	.1560	.1565							
		Arm Brg. (PN 652309 Prior Chg. "C")	ID	.160	.162	.0035	.006	.006@				
		(PN 652309 Prior Chg. "C")		.160	.162	.0035	.006	.014%				
		(PN 652309 Chg. "C" or Sub.)				.0005	.002	.002@				
		(PN 652309 Chg. "C" or Sub.)				.0005	.002	.014%				

@= Applicable OH Refurbishment Standards.

% = Applicable Repair Refurbishment Standards

* REF: AL... 72-71-6

PLANNER L. P... 4/22

DATE OF ISSUE 4/21/76

BX L/M [illegible] DATE 9/29/77

CX L/M [illegible] DATE 10-2-77

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ATTACHMENT C-3

ATTACHMENT C-4

VOLUME 9:DEPT. 955 9.1.6
CATEGORY 1:ORGANIZATION PAGE 1
ORIG.PUBL.: 2/09/71 2/09/77

ASSEMBLY AUDITS.

PURPOSE

To establish the procedure and responsibility for Dept. 955 internal audits.

SCOPE

All Engine/Rig memos, Operation and Measurement Sheets, Historical Records, Experimental Construction Procedures Volume 9, and Capital Equipment Utilization.

1. MEMOS,OPERATION AND MEASUREMENT SHEETS, AND HISTORICAL RECORDS

1.1 An audit of engine or rig memos, operation sheets, measurement sheets and the engine historical record will be made by a Supervisor on a daily basis.

1.2 The General Foreman will assign, to a Supervisor, the engine, rig and section to be audited.

1.3 When the Supervisor has completed the audit, he will record all discrepancies on Form EA 861 and return the form to the Supervisor whose engine records were audited.

1.4 The Supervisor shall question the assembler in charge of the engine or rig build on Assembly Floor procedures. Questions and answers will be recorded on the reverse side of the EA 861.

1.5 The Supervisor in charge of the audited engine records will investigate all discrepancies involving his shift, and

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record, on the back of the form, the names and clock numbers of the assemblers involved and the corrective action taken.

1.6 After corrective action is completed on his shift, the Supervisor will forward the EA 461 to the following two shifts, which will investigate their discrepancies in accordance with paragraph 1.5.

1.7 The last Supervisor after the inspection Supervisor will be responsible for filing the completed EA 461 form in the Assembly Records File at the General Foreman's desk.

Example: All first shift inspection records must be filed by the third shift.

All second shift inspection records must be filed by the first shift.

All third shift inspection records must be filed by the second shift.

1.8 Each Supervisor will sign his name in the upper right hand corner of the inspection form (EA 461) to verify that he has made the corrections for his shift.

1.9 Necessary corrections to the memo, operation sheets, etc., must be completed within the 24 hour period, and form EA 461 placed in the Assembly Records Inspection File, at the General Foreman's desk, for verification.

2. EXPERIMENTAL CONSTRUCTION PROCEDURES, VOLUME 9

2.1 All Experimental Construction Procedures, Volume 9 will be reviewed by Supervision on a yearly basis per schedule issued by the General Foreman's Clerk. Replies, changes, and deletions must, together with the proper justification, be returned to the

General Foreman within 10 working days from date of issue.

2.2 The General Foreman's clerk will maintain all records and take the necessary steps to see that changes, deletions, cancellations, etc., are corrected in the system.

3. CAPITAL EQUIPMENT UTILIZATION (REF: E.C.P. 1-12-4)

3.1 Capital equipment, with the exception of work benches, vises, cabinets, hoists, levelators and some small miscellaneous items, will be monitored for utilization.

3.2 Each piece of equipment will have a book attached for record purposes.

3.3 An audit of utilization records will be made semi-annually, in January and July of each year.

--- EOP ---.

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ATTACHMENT C-5

MEMO TO EXPERIMENTAL: ASSEMBLY X LINE NUMBER _____ TEST ☐ STAND NUMBER _____

PAGE 2

ASSEMBLERS OR TESTERS WILL ENTER CLOCK NO & DATE FOR WORK PERFORMED & WILL ENTER INITIALS & DATE FOR QUALITY ASSURANCE

WORK ORDER NO	ENGINE SECTION	MEMO TYPE	MEMO RELEASE DATE	MEMO SERIAL NUMBER
P-655713	COMP	MISC	6/17/77	76327

SALES NO	APE SALVAGE NO	ENGINEER	LOCATION	TEL EXT
79		BOUCHARD	3NT	5234

NUM	REQUIREMENTS	WORK DONE BY & DATE	QUALITY ASSURANCE & DATE
9	USE W.O. # 706060-3201 FOR LABOR. SEPARATE	~~6/5~~ 6/6	
	W.O. # FOR MATERIAL NOT REQ'D.	INFO	
10.	ACCEPT ENGINE ASSY. FROM SOUTHINGTON SERVICE CENTER.		
11.	ACCEPT THE FOLLOWING STATION 2.4 - 2.6/3.0 PROBES FROM AREA 86:		
	✓ 4 EA P/N 705518		
	✓ 3 EA P/N 705517		
	✓ 1 EA SKT 30820A		
	✓ 2 EA T 619808		
	✓ 2 EA T 619809		
	✓ 2 EA T 619810		
	✓ 2 EA T 619811		
12	INSTALL PROBES FROM ITEM 11 ABOVE PER PAGES 2 & 8 OF JT9D ENGINE INSTRUMENTATION MANUAL DATED 1/1/77. RECORD PROBE S/N & LOCATION.	PARTIAL 6/8 133236	
13.	INSTALL BELL CRANK POTENTIOMETER SUPPLIED BY ENGINEER.	6/5 133235	
14.	GET INSTRUMENT LAB TO NULL OUT POTENTIOMETER.	6/5 133235	
15	HOOK UP INSTRUMENTATION PER MEMO	PARTIAL 6/4 133236	

FOREMAN SIGNATURE _____ DATE 6/5/77 NUMBER OF ITEMS 7

ATTACHMENT C-6

PRATT & WHITNEY AIRCRAFT GROUP

EXPERIMENTAL TEST DEPARTMENT PROCEDURES

DEPT. 66 TEST PROCEDURES

No. 8.3
Page 1 of 2
Issued 7-24-70
Revised 2/24/77

TITLE: X-8 STAND PRE-START PROCEDURE

1.0 PURPOSE

1.1 To establish a standard operating procedure for the pre-start checkoff list for gas turbine engines and to insure a systematic method and sequence of operation to protect personnel and equipment from injury and damage.

2.0 REFERENCE

2.1 X-8 Stand Operating Procedure ETDP 8.0.

3.0 SCOPE

3.1 This Procedure provides an itemized list of equipment and systems to be checked for proper working order and condition prior to each test stand start. This is not a complete listing of all items to be checked, but rather the more generally used items.

4.0 RESPONSIBILITY

4.1 The responsibility for carrying out this Procedure rests with the Area Foreman and stand engine tester.

5.0 INSTRUCTIONS

5.1 Test supervision shall assure that operating personnel are instructed in any specific deviations from normal operation.

5.2 Requests for deviations from normal operation must be written and signed by the Experimental Test Engineer on the M.T.E. The Area Foreman must be cognizant of and approve all deviations.

5.3 It is the responsibility of the stand engine tester to review or double check each item with his crew, primarily the lead assistant tester, and in some cases the engine engineer prior to the first start of stand each shift the engine runs.

5.4 The X-8 Pre-Start Checkoff List is to be completed by the stand engine tester and his crew prior to every start.

5.4.1 When engine is operating at change of shift, the crew is to be briefed by Test Engineer on progress, engine operating limits and emergency shutdown procedures.

	1R	2R	3rd
Approval		Concurrence	
Lead M.A. 12-1-76	MGP 12-13-76	2/18/77	

ORIGINAL PAGE IS OF POOR QUALITY

TITLE: X-8 STAND PRE-START PROCEDURE

5.0 INSTRUCTIONS (Cont'd.)

5.5 The stand engine tester will check off each item after reviewing it with his crew or after sending a crew member into the stand for a double check and he will sign and date the bottom of the checkoff list in the space provided.

5.6 Any item that is not applicable will be so noted by N/A opposite the item rather than a check.

5.7 The X-8 Pre-Start Checkoff Lists will always include the normal sequence of events up through and including turning on the running lights.

5.8 Once the check list is completed by the operator, the area foreman will initial the check list indicating his approval.

6.0 PRE-START CHECK LIST X-8 STAND

6.1 See Pre-Start Checkoff List.

7.0 RETENTION

7.1 The completed checkoff list will be kept on the stand in the booklet described in Paragraph 4.2 of X-8 Stand Operating Procedure

7.2 One completed check list and one active check list form will be kept on the stand.

ATTACHMENT C-6 (Cont'd.)

PRATT & WHITNEY AIRCRAFT GROUP

EXPERIMENTAL TEST DEPARTMENT PROCEDURES

DEPT. 956

NO. 8.3.1
PAGE 1 of 6
ISSUED 7-29-70
REVISED 2/14/77

TITLE: X-8 TEST STAND PRE-START CHECKOFF LIST

ENGINE NO. _____
SET NO. 1

A. ENGINE INLET INSPECTION

1. Engine inlet to be inspected by two teams - operator and assistant operator, engineer and foreman if any one of the following conditions apply:
   a. Initial start.
   b. Each and every start when fan ducts are off.
   c. First start after fan ducts have been installed.
   d. First start after any type of work involving the engine inlet area.

	Engine Tester's Name	Foreman's Initials	Eng's Initials	Date	Time
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

B. ENGINE LEAK CHECK

1. Prepare engine and stand for fuel and oil systems leak check before initial start or first start after extensive engine changes.
   a. Pressurize without motoring engine.
   b. Pressurize and motor engine for 5 seconds, IGNITION OFF - SUPPRESSION WATER ON.
   c. Check for leaks per
   d. If no leaks, run per engineer's instructions.

	Operator's Name	Date	Time	Type and Location of Leak
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

APPROVAL				CONCURRENCE		
				1R	2R	3rd

PWA FORM 4487 REV 1-71
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ATTACHMENT C-6 (Cont'd.)

PRATT & WHITNEY AIRCRAFT GROUP

EXPERIMENTAL TEST DEPARTMENT PROCEDURES

DEPT. 956

NO. 8.3.1.
PAGE 2 of 6
ISSUED 7-29-70
REVISED 2/14/77

TITLE: X-8 STAND RE-START CHECKOFF LIST

ENGINE
SET NO. 1

C. ENGINE OPERATING AT SHIFT CHANGE AND RELIEF PERIODS

1. Change of shift crew and/or relief crew to be briefed by test engineer and operator on program, engine operational limits and emergency shut-down procedures.

	Running Operator's Signature	Relief Operator's Signature	Date	Time
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				
11.				
12.				
13.				
14.				
15.				
16.				
17.				
18.				
19.				
20.				

PRATT & WHITNEY AIRCRAFT GROUP

EXPERIMENTAL TEST DEPARTMENT PROCEDURES

DEPT. 956 TEST PROCEDURES

TITLE: X-8 TEST STAND PRE-START CHECKOFF LIST

ENGINE NO. P-743
SET NO. 1

		1	2	3	4	5	6	7	8	9	10	11	12
E.	**OUTSIDE AREA**												
1.	Select correct type of fuel, other types off.	✓	✓	✓									
2.	Cell inlet screen clean and clear	✓	✓	✓									
3.	Inlet curtain open and visually check.	✓	✓	✓									
4.	Demineralized water system ready for operation.	N/A	N/A	N/A									
5.	Inspect fuel lines and filters.	✓	✓	✓									
6.													
7.													
F.	**ROOF AREA**												
1.	Inspect gas control hours (normal running).	N/A	N/A	N/A									
1.1	Natural gas main valve on roof off.	N/A	N/A	N/A									
1.2	Natural gas valve in control house off.	N/A	N/A	N/A									
2.													
3.													
G.	**CELL INLET INSPECTION**												
1.	Inlet area.	✓	✓	✓									
2.	Heater burner inspection, check for loose material and for cracks.	✓	✓	✓									
3.	Heated inlet Thermo-Couple (T.C.) traverse rake in up position.	✓	✓	✓									
4.	Purge louver operation, condition and position.	✓	✓	✓									
5.	Engine inlet and inlet frame.	✓	✓	✓									
6.	Slipring air supply valve on.	N/A	N/A	N/A									
7.	Fan handling beam forward.	✓	✓	✓									
8.	Front platform down.	N/A	N/A	N/A									
9.	Close inlet cell doors.	✓	✓	✓									
10.													
11.													

PRATT & WHITNEY AIRCRAFT GROUP

EXPERIMENTAL TEST DEPARTMENT PROCEDURES

DEPT. 956 TEST PROCEDURES

TITLE: X-8 TEST STAND PRE-START CHECKOFF LIST

Engine No. P-743
Set No. 1

H. TEST CELL

		1	2	3	4	5	6	7	8	9	10	11	12
1.	Proper type of oil and tank filled to proper level.	✓	✓	✓									
2.	Check Power Lever Arm and Condition Lever Arm for proper operation and travel. Assistant to actuate both levers at control desk during checks. Both shafts should rotate full travel in both directions.	✓	✓	✓									
3.	Cover removed from ejector.	✓	✓	✓									
4.	Secondary air & ejector plug open or as engineer's requested.	✓	✓	✓									
5.	Inspect secondary air area.	✓	✓	✓									
6.	Pressure on to hydraulic lock pins.	N/A	N/A	N/A									
7.	Inspect engine hardback for proper safety of upper and lower front mount bolts (Snap rings-cotter pins-D-70 safety fixture).	✓	✓	✓									
8.	Inspect engine hardback for proper safety of upper and lower rear mount bolts (Snap rings-cotter pins).	✓	✓	✓									
9.	Inspect engine front mount bolts for proper installation and safety.	✓	✓	✓									
10.	Inspect engine rear mount bolts for proper installation and safety.	✓	✓	✓									
11.	Inspect four (4) sling or spacer mount pins for proper insertion and safety.	✓	✓	✓									
12.	Inspect four (4) hardback mount pins for proper insertion and safety.	✓	✓	✓									
	NOTE: Pay particular attention to any area where other departments have made changes and may have disrupted safety provisions.	✓	✓	✓									
13.	Slip ring air on.	N/A	N/A	N/A									
14.	Stack clean and door closed.	✓	✓	✓									
15.	Visual engine inspection & instrumentation secured.	✓	✓	✓									
16.	Bulkhead doors closed and locked.	✓	✓	✓									
17.	Fuel valve (sample) closed and capped.	✓	✓	✓									
18.	Fuel scavenge on automatic.	✓	✓	✓									
19.	Ejector flare set to 50% or as requested by engineer.	✓	✓	✓									
20.	Tie fan hoists to rear of cell, clear of water line and secondary air.	N/A	N/A	N/A									

ATTACHMENT C-6 (Cont'd.)

PRATT & WHITNEY AIRCRAFT GROUP

EXPERIMENTAL TEST DEPARTMENT PROCEDURES

NO. 8.3.1
PAGE 5 of 6
ISSUED 7-29-70
REVISED 2/14/77

DEPT. 956 TEST PROCEDURES

TITLE: X-8 TEST STAND PRE-START CHECKOFF LIST

ENGINE NO. P-743
SET NO. 1

H. TEST CELL (Cont'd)

		1	2	3	4	5	6	7	8	9	10	11	12
21.	Tie fan hoists rails to permit steam extinguisher operation.			✓									
22.	All hoists secured plus hoists beams in ejector.	✓	✓	✓									
23.	Two (2) lift platforms down, unless needed for idle check.			✓									
24.	Cooling air on to vane, hydronic pots, ignition harnesses and starter.	✓	✓	✓									
25.	Turn off cell heaters.	✓	✓	✓									
26.	Clear cell of all personnel, close doors and man until running lights are turned on.	✓	✓	✓									
27.													

I. CONTROL ROOM

1.	Data sheets complete & ready for use.	✓	✓	✓									
2.	Know your program and nature of run.	✓	✓	✓									
3.	Brief data takers on all engine limits listed on mount sheet or noted in the M.T.E. Remind each data taker of the appropriate action to take when it is exceeded.	✓	✓	✓									
3.1	Verify that all engine operating limits are posted in front of data taker responsible for monitoring and recording limit parameter.			✓									
3.2	Verify that all engine operating limits are noted on top of the data sheet where parameter is recorded.			✓									
3.3	Brief crew on duties and any special assignments.	✓	✓	✓									
4.	Calibrate thrust meter readouts visual and Astro Data System.	✓	✓	✓									
5.	Calibrate fuel and water readouts.	✓	✓	✓									
6.	Calibrate all digital readouts.	✓	✓	✓									
7.	Correct fuel type-light on.	✓	✓	✓									
8.	Contact data central on readiness of system.	✓	✓	✓									
9.	Power on 24 Volt and 400 cycle.	✓	✓	✓									
10.	Slipring air on and pressure reading.												
11.	Brush lifter air reading.												
12.	Turn on & clear engine annunciator panel.	✓	✓	✓									
13.													
14.													

ATTACHMENT C-6 (Cont'd.)

PRATT & WHITNEY AIRCRAFT GROUP

EXPERIMENTAL TEST DEPARTMENT PROCEDURES

NO. 8.3.1
PAGE 6 of 6
ISSUED 7-29-70
REVISED 2/14/77

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DEPT. 956 TEST PROCEDURES

TITLE: X-8 TEST STAND PRE-START CHECKOFF LIST

ENGINE NO. P-743
SET NO. 1

I. CONTROL ROOM (Cont'd.)

		1	2	3	4	5	6	7	8	9	10	11	12
13.	Check stack water interlock to ignition.	✓	✓	✓									
14.	Check all indicating lights.	✓	✓	✓									
15.	Check operation of steam fire system.	✓	✓	✓									
16.	Engine bleeds properly set per engineer.	✓	✓	✓									
17.	Power to Gas Alarm & cleared.	✓	✓	✓									
18.	Heated inlet T.C. rake up (light).	✓	✓	✓									
19.	Natural gas (Methane) off and purge louvers closed.	✓	✓	✓									
20.	Turn on fuel valves.	✓	✓										
20.1	Pressurize & motor engine for fuel system leak check.	✓	✓	NA									
21.	Call foreman for initial on first start after extensive engine changes.	✓	NA	✓									
	NOTE: Heated inlet operation on heated inlet procedures.												
22.													
23.													
24.	TIME	9:27 AM	9:27 AM	9:12 PM									
25.	DATE	9-8-77	9-8-77	9-12-77									
26.	ENGINE TESTER'S SIGNATURE Operator's signature will signify that the equipment inspected or function performed is fully satisfactory for test.	S. Arvai	S. Arvai	S. Arvai									
27.	STAND DECLARED READY TO RUN Foreman's signature indicates approval of pre-start check list.	[illegible]	[illegible]	[illegible]									

PWA FORM 4487A NEW 1/71

ATTACHMENT C-7

Pratt & Whitney Aircraft DIVISION OF UNITED AIRCRAFT CORPORATION
EAST HARTFORD 8, CONNECTICUT

EXPERIMENTAL ENGINEERING

INSTRUMENTATION STANDARDS & PROCEDURES

No. 3:3101
Page 1 of 6
Date 5-21-70
Rev. A-4-10-74

ASTRODATA STEADY STATE DATA SYSTEM (SSDS) CERTIFICATION

1.0 SCOPE

The purpose of this procedure is to document the means which are used to certify the accuracy and precision of the Astrodata Steady State Data System.

2.0 INTRODUCTION

This system consists of a central on-line computer, central interface controller, and local sub-systems which acquire data from test stands. The availability of on-line computing capability permits a flexibility in the application of sensor calibrations to the recorded data, and permits statistical evaluation of the precision of measurement.

Both the pressure measuring equipment and the low voltage measuring equipment sense output under zero conditions concurrent with test measurements. These test measurements are automatically corrected for zero offset, which is a parallel shift of the input-output relationship of the equipment.

Two methods of calibration are possible.

2.1 Certified reference parameters may be applied to selected channel inputs ("confidence channels") during acquisition of test data. This is referred to as "concurrent" calibration.

2.2 Certified reference parameters may be applied to selected channel inputs prior or subsequent to acquisition of test data. Static readings or system scans are taken for the sole purpose of acquiring the calibration data. This is referred to as "nonconcurrent" calibration.

Any combination of the two techniques is acceptable, provided all performance data parameters are recorded using certified equipment.

3.0 EQUIPMENT AND MATERIALS

Equivalents may be used provided they are certified to the required accuracy.

3.1 Certification Required

J.W.C. 5-23-72	JQG 5-26-72	Hmp 5-30-72	B 4-17-74 6-14-72	Lmc 6-17-74

ATTACHMENT C-7 (Cont'd.)

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ASTRODATA STEADY STATE DATA SYSTEM (SSDS) CERTIFICATION

3.1.1 Ametek dead weight testers of appropriate range.

3.1.2 Texas Instruments Precision Pressure Gages (PPG's) of appropriate range.

3.1.3 Claude S. Gordon Ice Reference Unit with thermocouple wire pairs of appropriate material.

3.1.4 Astrodata P/N 25469 - mv source

3.2 Certification Not Required

3.2.1 Regulated pressure source

3.2.2 Mechanical vacuum pumps (2)

3.2.3 Data sheets as appropriate

3.2.4 Pressure vessel with [illegible] cu. ft. mimimum volume

4.0 INSTRUCTIONS AND PROCEDURES

4.1 Pressure

*4.1.1 Concurrent Calibration

Certified Ametek pneumatic dead weight tester output pressures are connected to the SSDS pressure channels such that each SSDS pressure transducer scans one or more known pressures appropriate to its range during each data scan. This data is recorded in the same manner as test data. The barometric transducer for the local sub-system must be calibrated by I.S.&P. 3:3269 to complete the certification of absolute pressure transducers against a pressure standard such as the Texas Instr. Precision Pressure Gage.

ATTACHMENT C-7 (Cont'd.)

*4.1.2 Nonconcurrent Calibration (I.S.P. 3:3269)

Standard pressures are applied to each data system pressure transducer. The standards used to determine these pressures are the Ametek dead weight tester (barometric reference) and the Texas Instruments PTS (Hard vacuum reference). Several pressure increments of the transducer full scale reading are set and the system output is measured on a DVM.

4.2 Frequency

4.2.1 Concurrent Calibration

This type calibration is not used because a given frequency channel is not commutated between several frequency signals.

*4.2.2 Nonconcurrent Calibration (I.S.P. 3:3270)

Each frequency channel is certified by comparing the system readout with that of a certified counter when both are reading the output frequency of an audio oscillator. Typically, several frequencies in the 0-10K Hz range are recorded.

4.3 Thrust

4.3.1 Concurrent Calibration

Not used.

4.3.2 Nonconcurrent Calibration (I.S.P. 3:3205)

The thrust channels are certified by recording the system output in the R-cal mode. The R-cal values are determined by the referenced IS&P.

Thrust is recorded on two frequency channels.

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ASTRODATA STEADY STATE DATA SYSTEM (SSDS) CERTIFICATION

4.4 D.C. Voltage

4.4.1 Concurrent Calibration

A single millivolt channel from each system multiplexer is used to record the millivolt output of the standard millivolt source (Astrodata P.N. 25469) assigned to the system substation. These "confidence channels" are recorded concurrently with all engine test data.

4.4.2 Nonconcurrent Calibration

Each emf (millivolt) channel is calibrated by comparing the system readout with the input from each of the SSDS standard voltages daily. This calibration data is used to correct the test data automatically.

4.5 Temperature

4.5.1 Concurrent Calibration

The outputs of certified thermocouple wire pairs with one junction in a certified Ice Reference Unit are used to determine the temperature of the reference junction blocks. Additional similar thermocouple wire pairs are also used with one junction at the ice reference unit and the other at the reference junction block to verify that the system records correctly the temperature of the ice reference unit.

4.5.2 Nonconcurrent Calibration (I.S.&P. 3:3243)

Working thermocouples are calibrated by the referenced I.S.&P. when fabricated. This calibration data is stored in the system.

5.0 DISPOSITION OF DATA

All concurrent and nonconcurrent calibration data is reviewed by Engineering.

ATTACHMENT C-7 (Cont'd.)

ASTRODATA STEADY STATE DATA SYSTEM (SSDS) CERTIFICATION

5.1 Concurrent Calibration

No intervals are established for concurrent calibration because of its nature. Refer to 2.0.

5.2 Nonconcurrent Calibration

The intervals establish for nonconcurrent calibration are as follows:

*5.2.1 Pressure 2 months per IS&P 3:3269

*5.2.2 Frequency 6 months per IS&P 3:3270

5.2.3 Thrust each installation per IS&P 3:3205
3:3206 for Hydraulic Load Cells

5.2.4 D.C. mv each day

5.2.5 Temperature (TC's when fabricated) per IS&P 3:3243

5.3 All nonconcurrent certification data will be retained by the Cognizant Instrumentation Group.

5.4 All concurrent certification data will be retained by the engine group as part of the engine log file.

*5.5 A white calibration sticker will be displayed on the nonconcurrent and concurrent data printouts.

ATTACHMENT C-7 (Cont'd.)

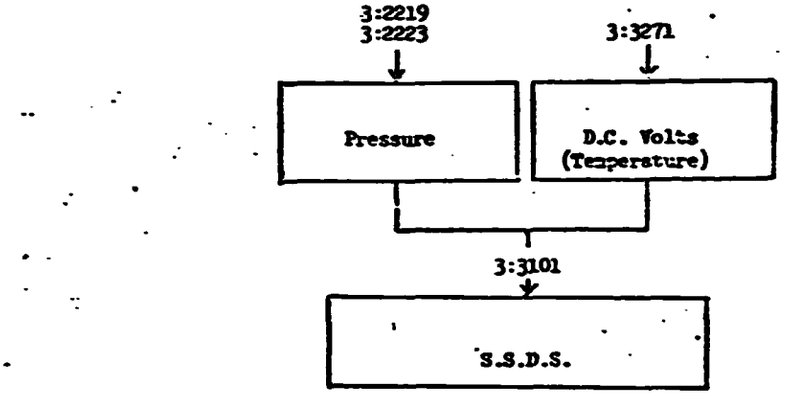
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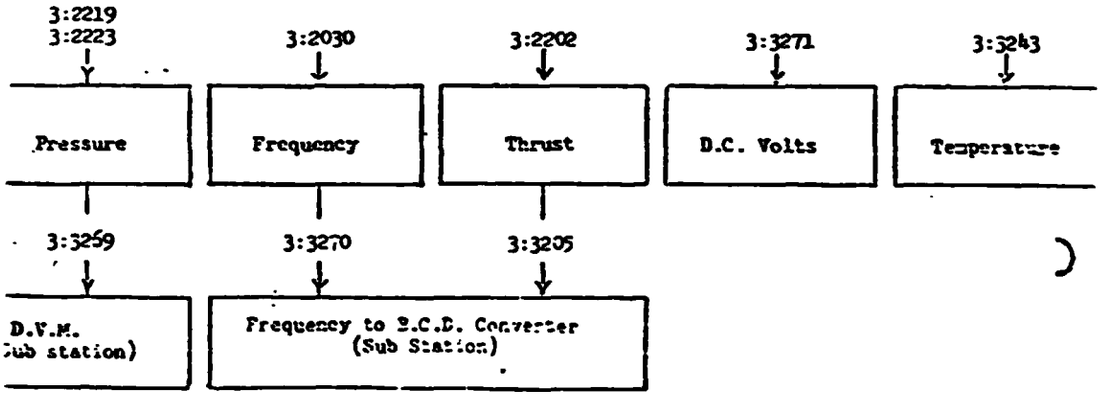
ASTROMATA STEADY STATE DATA SYSTEM (S.S.D.S.) CERTIFICATION

Traceability Chart

CONCURRENT CALIBRATIONS



NON-CONCURRENT CALIBRATIONS



Pratt & Whitney Aircraft

TEST STAND THRUST SYSTEM CALIBRATION
APPLICABLE ISBP NUMBER
3:3205

STAND B
BRIDGE X-Y
K 6
DATE 9-10-77

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ATTACHMENT C-8

EXPERIMENTAL ENGINEERING STANDARDS LABORATORY

CALIBRATION THRUST-LBS (K)	THRUST METER LBS	FREQUENCY HZ	FREQ X K	CORRECTION (1) - (4)		AVE CORR.	HYSTERESIS
(1)	(2)	(3)	(4)	(5)		(6)	(7)
0	0	0	0	0	0	0	0
12	11999	1997	11982	+18	+24	+21	6
24	23987	1995	23970	+30	+36	+33	6
36	35993	1996	35976	+24	+24	+24	0
48	48000	8000	48000	0	0	0	0
60	60012	10006	60036	-36	-24	-30	12
61	61011	10173					
60	60008	10004	60024				
48	47992	8000	48000				
36	35988	5996	35976				
24	23987	3999	23964				
12	12002	1996	11976				
0	0	0	0				

TOLERANCE FOR CORRECTED CAL: COL (6) 0.1% F.S
COL (7) 0.1% F.S.

THRUST HISTORY DATA

STAND	ENGINE TYPE	ENGINE NUMBER	BRIDGE	K	DATE	TIME	EXCITATION	MV. R-CALS 0	MV. R-CALS #1	MV. R-CALS #2	MV. R-CALS #3	FREQ. R-CALS 0	FREQ. R-CALS #1	FREQ. R-CALS #2	FREQ. R-CALS #3	LOAD CELL TEMP	CAL CELL R-CAL	CABLE	CAL CELL CODE	F.S. (K)	AS-IS
1	4	9		16		22	26	33	36	41	46	51	54	58	62	66	69	75			80
X-B	JT-9D	P-743	BB	6	9 10 77	0630	116647		46752	26753	64611	00	80421	12602	50			4	6	C	C

	POINT #1, 7		POINT #2, 8		POINT #3, 9		POINT #4, 10		POINT #5, 11		POINT #6, 12		MAX PT	
	FREQ	CAL THRUST	FREQ	CAL THRUST	FREQ	CAL THRUST	FREQ	CAL THRUST	FREQ	CAL THRUST	FREQ	CAL THRUST	FREQ	CAL THRUST
1	11		21		31		41		51		61		71	

APPROVAL: TEST ENGINEER _____
INST. LAB. FOREMAN _____
DATA RECORDED BY _____

APPENDIX D

FUEL ANALYSES

PRATT & WHITNEY AIRCRAFT GROUP — UNITED TECHNOLOGIES

MATERIALS ENGINEERING & RESEARCH LABORATORY

ACCOUNT NO.	706067-3201
LAB. NO.	L-274
DATE REQUESTED	9-13-77
DATE RELEASED	9-20-77

REQUESTED BY: R. Bouchard	DEPARTMENT: Eng. EB 3J
SEND REPORTS TO: R. Bouchard, A. Davis	
PART NAME: Jet Fuel	MATERIAL: Jet A
PART NUMBER:	HEAT CODE: / SERIAL NO.:
ENGINE TYPE: JT9D-7A(SP) / NO.: P743-01	MFG.:
PART TIME:	OPERATED BY:

WORK REQUESTED:

Specific Gravity and HOC

Results				S.G. 60/60F	HOC Net Btu/lb.
Sample	9-12	0930	Start	.8072	18,564
	9-12	–	End	.8072	18,552

REPORTED BY: A. Bailey, R. Wexler	APPROVED BY: J. H. Sizer 3146

PWA FORM 281 REV. 3-73

PRATT & WHITNEY AIRCRAFT GROUP
Government Products Division

MATERIALS ENGINEERING & RESEARCH LABORATORY

ACCOUNT NO.	184751
LAB. NO.	77-200-7080-Z
DATE REQUESTED	8/05/77
DATE RELEASED	8/24/77

REQUESTED BY	A. Durgin
DEPARTMENT	Building 410, Middletown
SEND REPORTS TO	A. Ebstein, R. Bouchard, J. Kimball
PART NAME	Jet Fuel
MATERIAL	ASTM D-1655, Jet A
PART NUMBER	
HEAT CODE	
SERIAL NO.	
ENGINE TYPE	JT9D, 7ASP
NO.	P-695743
MFG.	
PART TIME	
OPERATED BY	

WORK REQUESTED:

Specific gravity and heat of combustion.

Results:

Sample Date	Engine No.	Calibration	S.G. 60/60F	HOC, Net, Btu/lb.
7/28	695743	Pre	0.8123	18,520
7/28	695743	Post	0.8128	18,535
8/01	695743	Pre	0.8128	18,540
8/01	695743	Post	0.8128	18,525
8/02	695743	Pre	0.8128	18,515
8/02	695743	Post	0.8123	18,525

REPORTED BY	A. Bailey, R. Wexler
APPROVED BY	J. Sizer

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APPENDIX E

PRODUCTION STAND LOG SHEET SUMMARIES

SUMMARY

LOG OF ENGINE TEST

ENGINE # P695743 JT9D-7ASP CELL # 4 DATE 7/26/77 TIME 2110

ENGINEERING REQUIREMENTS

FN/ST2	TSFC % DEVIATION
44150.	1.1
40000.	1.0
37275.	1.1

As Rec'd Cal. (Prior To Trim)

SUMMARY

LOG OF ENGINE TEST

ENGINE # P695743 JT9D-7ASP CELL # 4 DATE 7/29/77 TIME 1525

ENGINEERING REQUIREMENTS

FN/ST2	TSFC % DEVIATION
46150.	.8
40080.	.7
37275.	.8

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As Rec'd Cal (After Trim)

SUMMARY

LOG OF ENGINE TEST

ENGINE # P695743 JT9D-7ASP CELL # 4 DATE 8/ 1/77 TIME 2052

ENGINEERING REQUIREMENTS

FSLHV 18535.

FN/ST2	TSFC % DEVIATION
46150.	1.1
40080.	.7
37275.	.8

CAL AFTER H_2O WASH

SUMMARY

LOG OF ENGINE TEST

ENGINE # P695743 JT9D-7ASP CELL # 4 DATE 8/ 1/77 TIME 2201

ENGINEERING REQUIREMENTS

FSLHV 18535.

FN/ST2	TSFC % DEVIATION
46130.	1.1
40080.	1.0
37275.	1.1

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CAL AFTER H_2O WASH & RETRIM

SUMMARY

LOG OF ENGINE TEST

ENGINE # 0695743 JT9D-7ASP CELL # 4 DATE 8/ 2/77 TIME 1503

ENGINEERING REQUIREMENTS

FSLHV 18535.

FN/ST2	TSFC % DEVIATION
46150.	.5
40060.	.7
37275.	.8

CAL AFTER DETERGENT WASH (TWICE)

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APPENDIX F

EXPERIMENTAL STAND LOG SHEETS

X- 8 STAND ENGINE P-743- TIME 1131 DATE 09/12/77 AFTER 1880 HOURS SSDS ENGINE DATA-TEST ACQUISITION

JT9D-7A THUMBWHEELS 9-99999999-0 00-00-00000-0 ENGINEERING UNITS ON MAGNETIC TAPE ONLY

OPTIONS ARE SU9D - 0

S S U S R E L I A B I L I T Y S E C T I O N

MV CHANNELS:

MUX PRECISION VOLTAGE: MUX 0 2.499 MV MUX 1 2.499 MV MUX 2 2.500 MV

UTR NO.	1	2	3	4	5	6	7	8	9	10
VALUE MV	0.6828	0.6833	0.7709	0.7604	0.6793	0.6819	0.6928	0.6905	0.6847	0.9011
TEMP-DEGS F.	62.8420	62.8645	66.7819	66.3126	62.6852	62.8046	63.2924	63.1859	71.6627	72.5921
CONF-DEGS F.	31.8103	32.0349	32.1046	32.2043	31.8853	32.0590	32.0169	93.8640	31.6388	31.7864
DIFFERENCE	0.1897	-0.0349	-0.1046	-0.2043	0.1147	-0.0590	-0.0169	-61.8640*	0.3612*	0.2136

UTR NO.	11	12	13	14	15	16	17	18	19	20
VALUE MV	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9017
TEMP-DEGS F.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	72.6701
CONF-DEGS F.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
DIFFERENCE	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

PRESSURE CHANNELS:
SCANIVALVES FLAGGED BY SINGLE STARS ARE NOT USED FOR DATA.

SV NO.	1	2*	3	4*	5	6	7*	8*
RANGE	400.000	400.000	100.000	100.000	50.000	50.000	400.000	100.000
ZERO	1.560	0.840	0.450	0.280	0.150	0.125	0.760	0.390
CONF	319.800	319.920	79.970	79.980	39.985	40.005	319.840	80.010

SV NO.	9	10	11	12	13*	14*	15*	16*
RANGE	15.000	15.000	15.000	15.000	100.000	100.000	100.000	100.000
ZERO	0.190	0.039	0.421	0.093	0.240	0.220	0.350	0.140
CONF	12.001	11.998	11.994	11.998	80.020	80.040	80.010	80.030

SV NO.	17	18*	19	20*	21*	22*	23	24
RANGE	15.000	15.000	15.000	15.000	15.000	15.000	-99.826	-99.826
ZERO	0.105	0.100	0.135	0.021	0.026	0.112	1.008	3.274
CONF	12.001	11.994	11.998	12.001	12.001	12.003	-79.561	-79.581

BAROMETER ZERO: 0.000

BAROMETER PRESSURE: 2057.350

FREQUENCY CHANNELS:
THRUST METER DIFFERENCE IS 0.36 COUNTS. FUEL METER DIFFERENCE IS 0.069%.

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X-  0 STAND  ENGINE P-743-     TIME 1131  DATE 09/12/77  P&WA ENGINE TEST LOG - DATA SYSTEM CERTIFIED BY ISAP 3:3101

 JT9D-7A    AFTER 1000 HOURS                  BELLMOUTH TYPE  2    THUMBWHEELS  9 9 9 9 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0

FIELD NO       1          2          3          4          5          6          7          8          9          10
0X-  0 P-743-    0 JT9D-7A 091277 1856085 AFTER 1000 HOURS                    00000000
100000.005560.0000000 2   0    0    0   00100000 200000 000000 00 4000000100000000
2 000.920 121.30 000000 000000.000.000000050000010000000200000. 00

PARAMETER                                  BARO 2
CARD  2     0.0000     0.0000     0.0000   2114.6992    14.0161     0.0000     0.0000     0.0000     0.0000     0.0000

PARAMETER  COX1TEMP   COX2TEMP                                                TT3 MN S                BEMPOINT
CARD  3     83.1571    82.8911     0.0000     0.0000     0.0000     0.0000   221.8535     0.0000    36.3911     0.0000

PARAMETER  AVG N1     AVG N2     A FN A                 BFN MISC                                    A FN B
CARD  4  3482.9941  7459.1572  7453.7568     0.0000     0.0000     0.0000     0.0000     0.0000  7654.1102     0.0000

PARAMETER             ACOX1CPS   COX1 CPG   ACOX2CPS   COX2 CPG
CARD  5     0.0000    857.9194  1140.6938    821.8395  1101.3982     0.0000     0.0000     0.0000     0.0000     0.0000

PARAMETER  TT1  1     TT1-2      TT1-3      TT1-4      TT1-5      TT1-6      TT1-7      TT1-8      TT1-9      TT1-10
CARD  6     66.9161    66.6478   105.1362*    66.2653    66.0424    66.1556    66.6697    66.7706    66.3323    66.1981

PARAMETER  TT1-11     TT1-12     TT1-13     TT1-14     TT1-15     TT1-16     TT1-17     TT1-18     TT1 19     TT1 20
CARD  7     65.9506    66.1726    67.0892    66.8685    66.2716    66.8923    66.4996    65.7542    66.0518    67.0895

PARAMETER  TT1 21     TT1 22     TT1 23     TT1 24
CARD  8     66.4684    66.3167    66.2978    66.0378     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000

PARAMETER  TT2.6 B1   TT2.6 B2   TT2.6 B3   TT2.6 B4   TT2.6 B5   TT2.6 D1   TT2.6 D2   TT2.6 D3   TT2.6 D4   TT2.6 D5
CARD  9   147.8493   156.3654   144.7485   137.8068   138.7603   155.1762   142.1796   143.5838   139.1874   131.5277

PARAMETER  TT2.6 F1   TT2.6 F2   TT2.6 F3   TT2.6 F4   TT2.6 F5   TT2.6 M1   TT2.6 M2   TT2.6 M3   TT2.6 M4   TT2.6 M5
CARD 10   155.9148   146.8378   148.6723   134.7139   136.3602   154.3458   144.3222   141.4112   138.2594   131.4466

PARAMETER  CONF 1     CONF 2     CONF 3     CONF 4     CONF 5     CONF 6     CONF 13    CONF 14    CONF 9     CONF 10
CARD 14    31.9103*   32.0349*   32.1046*   32.2843*   31.8853*   32.8598*   32.8169*   93.8648*   31.6388*   31.7864*

PARAMETER             PT7 A      P BKHD F   P BKHD F   P BKHD F   P BKHD F   P BKHD A   P BKHD A   P BKHD A   P BKHD A
CARD 16     0.0000     7.8515    -1.1388    -0.9384    -0.9983    -0.9483    -1.8881    -1.8981    -1.8182    -1.8881

PARAMETER  PT3 A      PT3 A      PT3 A      PT3 A      PT3 A      PT3 C      PT3 C      PT3 C      PT3 C      PT3 C
CARD 17    17.6686    23.3458    20.2188    20.2788    20.8958    17.8888    20.3158    20.8188    20.9388    21.2258

PARAMETER  PT3 E      PT3 E      PT3 E      PT3 E      PT3 E      PT3 G      PT3 G      PT3 G      PT3 G      PT3 G
CARD 18    17.7888    20.1188    20.3888    20.9288    18.3258    17.6688    20.0888    19.7758    21.6358    18.8458

PARAMETER                                                                                 PS4I       PB         PS5I
CARD 20     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000   281.2399   299.2399   20?.9599

PARAMETER  PT4 A      PT4 A      PT4 A      PT4 C      PT4 C      PT4 C
CARD 21   311.5599   317.1199   318.7999   312.1999   317.7199   311.7599     0.0000     0.0000     0.0000     0.0000

FIELD NO       1          2          3          4          5          6          7          8          9          10
```

X- 8 STAND ENGINE P-743- TIME 1131 DATE 09/12/77 P&WA ENGINE TEST LOG - DATA SYSTEM CERTIFIED BY ISAP 3:3101

JT9D-7A AFTER 1000 HOURS BELLMOUTH TYPE 2 THUMBWHEELS 9 9 9 9 9 9 9 9 8 8 8 8 8 8 8 8 8 8

FIELD NO	1	2	3	4	5	6	7	8	9	10
PARAMETER	PT4 E	PT4 E	PT4 E	PT4 G	PT4 G	PT4 G				
CARD 22	321.6799	315.1199	307.5999	321.8799	315.4399	307.8799	0.0000	0.0000	0.0000	0.0000
PARAMETER	CONF 1A	CONF 2A	CONF 3A	CONF 4A	CONF 5A	CONF 6A	CONF 13A	CONF 14A	CONF 9A	CONF 10A
CARD 23	31.9821•	31.9861•	31.9439•	32.0919•	31.9869•	31.8368•	32.0238•	31.9665•	32.0319•	31.9259•
PARAMETER	PT12.5									
CARD 24	-0.0338•	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
PARAMETER	PT26 A	PT26 A	PT26 A	PT26 A	PT26 A	PT26 C	PT26 C	PT26 C	PT26 C	PT26 C
CARD 25	7.8858	8.5298	8.1698	7.4283	6.9688	6.8875	8.9385	8.5335	7.5128	6.7658
PARAMETER	PT26 E	PT26 E	PT26 E	PT26 E	PT26 E	PT26 G	PT26 G	PT26 G	PT26 G	PT26 G
CARD 26	8.6585	8.8198	7.9755	7.5188	6.6645	8.3948	8.5148	7.9755	7.3515	5.9978
PARAMETER	TT6-A		TT6 C		TT6 E					
CARD 27	1733.9421	0.0000	1589.8335	0.0000	1639.1891	0.0000	0.0000	0.0000	0.0000	0.0000
PARAMETER	3.5TR	3.5QR	3.5TL							
CARD 28	-0.0158	-0.0458	-0.0488	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
PARAMETER	TT4@ORE3									
CARD 29	937.7294	0.0000•	0.0000•	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
PARAMETER	PT2 PS	PT2 PS	PT2 PS	PT2 PS	PT2 PS	PT2 PS	PT2 PS	PT2 PS		
CARD 30	-1.8869	-1.6671	-1.8268	-3.2144	-2.8165	-1.8468	-1.6671	-1.6571	0.0000	0.0000
PARAMETER	PS2 PS	PS2 PS	PS2 PS	PS2 PS	PS2 PS	PS2 PS	PS2 PS	PS2 PS		
CARD 31	-80.9891	-79.9288	-79.4317	-79.1921	-78.8141	-78.2138	-78.7229	-80.6495	0.0000	0.0000
PARAMETER	PT24 A	PT24 A	PT24 A	PT24 A	PT24 A	PT24 A	PT24 A	PT24 A		
CARD 32	8.6368	8.6878	8.6138	8.5635	8.2858	7.6425	7.4738	7.2185	0.0000	0.0000
PARAMETER	PT24 B	PT24 B	PT24 B	PT24 B	PT24 B	PT24 B	PT24 B	PT24 B		
CARD 33	8.4985	8.9565	8.9625	8.7375	8.2245	7.6598	7.3418	7.0238	0.0000	0.0000
PARAMETER	PT24 C	PT24 C	PT24 C	PT24 C	PT24 C	PT24 C	PT24 C	PT24 C		
CARD 34	8.8415	8.8215	8.8418	8.6788	8.3775	7.9885	7.6635	7.2218	0.0000	0.0000
PARAMETER	PT24 D	PT24 D	PT24 D	PT24 D	PT24 D	PT24 D	PT24 D	PT24 D		
CARD 35	8.3565	8.6825	8.7998	8.5888	8.1988	7.6425	7.3985	7.0485	0.0000	0.0000
PARAMETER	PT24 E	PT24 E	PT24 E	PT24 E	PT24 E	PT24 E	PT24 E	PT24 E		
CARD 36	7.7985	9.5228	9.3845	9.8458	8.6115	8.8985	7.8195	7.3155	0.0000	0.0000
PARAMETER	PT24 F	PT24 F	PT24 F	PT24 F	PT24 F	PT24 F	PT24 F	PT24 F		
CARD 37	8.3565	8.6925	8.538.	8.2328	7.9365	7.3995	7.1798	6.9758	0.0000	0.0000
FIELD NO	1	2	3	4	5	6	7	8	9	10

H- 8 STAND ENGINE P-743- TIME 1131 DATE 09/12/77 P&WA ENGINE TEST LOG - DATA SYSTEM CERTIFIED BY ISSP 3:3101

JT9D-7A AFTER 1000 HOURS BELLMOUTH TYPE 2 THUMBWHEELS 9 9 9 9 9 9 9 9 9 8 8 8 8 8 8 8 8 8 8

FIELD NO	1	2	3	4	5	6	7	8	9	10
PARAMETER	PT24 G	PT24 G	PT24 G	PT24 G	PT24 G	PT24 G	PT24 G	PT24 G		
CARD 38	8.2985	8.5208	8.6535	8.3828	8.2448	7.7618	7.4655	7.0815	8.0000	8.0000
PARAMETER	PT24 H	PT24 H	PT24 H	PT24 H	PT24 H	PT24 H	PT24 H	PT24 H		
CARD 39	8.3445	8.6288	8.6108	8.3558	8.1278	7.5555	7.3718	7.0905	8.0000	8.0000
PARAMETER	TT24 A	TT24 A	TT24 A	TT24 A	TT24 A	TT24 A	TT24 A	TT24 A		
CARD 40	152.4588	156.3055	152.4982	145.7414	141.7545	139.4881	137.9758	135.1999	8.0000	8.0000
PARAMETER	TT24 B	TT24 B	TT24 B	TT24 B	TT24 B	TT24 B	TT24 B	TT24 B		
CARD 41	153.1117	162.8681	149.4863	146.2641	143.7194	140.5784	132.3898	130.9287	8.0000	8.0000
PARAMETER	TT24 C	TT24 C	TT24 C	TT24 C	TT24 C	TT24 C	TT24 C	TT24 C		
CARD 42	157.0048	156.3187	153.9655	146.8124	142.6168	141.6346	136.0883	132.2752	8.0000	8.0000
PARAMETER	TT24 D	TT24 D	TT24 D	TT24 D	TT24 D	TT24 D	TT24 D	TT24 D		
CARD 43	157.9813	159.1481	148.8676	144.7973	140.8191	141.5658	134.7851	131.4852	8.0000	8.0000
PARAMETER	TT24 E	TT24 E	TT24 E	TT24 E	TT24 E	TT24 E	TT24 E	TT24 E		
CARD 44	147.3927	161.9885	155.8289	149.8116	144.2327	143.2105	138.1586	133.9522	8.0000	8.0000
PARAMETER	TT24 F	TT24 F	TT24 F	TT24 F	TT24 F	TT24 F	TT24 F	TT24 F		
CARD 45	153.8188	159.8553	146.7642	142.8851	138.9926	139.3716	132.7336	130.8358	8.0000	8.0000
PARAMETER	TT24 G	TT24 G	TT24 G	TT24 G	TT24 G	TT24 G	TT24 G	TT24 G		
CARD 46	154.6869	155.9806	151.1953	146.5683	141.5483	139.8842	135.4917	130.7177	8.0000	8.0000
PARAMETER	TT24 H	TT24 H	TT24 H	TT24 H	TT24 H	TT24 H	TT24 H	TT24 H		
CARD 47	152.8122	157.8837	142.4829	144.4887	140.8417	141.2582	134.8855	131.5273	8.0000	8.0000
PARAMETER	PT6 B	PT6 D	PT6 F							
CARD 51	67.5188	65.9988	66.1488	8.0000	8.0000	8.0000	8.0000	8.0000	8.0000	8.0000
PARAMETER	TT3 B1	TT3 B2	TT3 B3	TT3 B4	TT3 B5	TT3 C1	TT3 D2	TT3 D3	TT3 D4	TT3 D5
CARD 56	220.9671	224.6026	222.1548	238.8418	263.5827	233.8466	225.5352	222.9615	232.7861	261.9269
PARAMETER	TT3 F1	TT3 F2	TT3 F3	TT3 F4	TT3 F5	TT3 H1	TT3 H2	TT3 H3	TT3 H4	TT3 H5
CARD 57	224.6295	222.4688	235.7515	247.1952	274.3971	227.7177	224.8388	226.7463	242.2357	273.6668
PARAMETER	A/C									
CARD 62	2.4347	8.8888	8.8888	8.8888	8.8888	8.8888	8.8888	8.8888	8.8888	8.8888
PARAMETER	TT4 B1	TT4 B3	TT4 B5	TT4 D1	TT4 D3	TT4 D5				
CARD 63	962.5322	937.3683	976.2275	968.2438	928.8384	978.8687	8.0000	8.0000	8.0000	8.0000
PARAMETER	TT4 F2	TT4 F4	TT4 F6	TT4 H2	TT4 H4	TT4 H6				
CARD 64	947.2875	951.8516	1025.6662	933.4848	928.5216	1888.8988	8.0000	8.0000	8.0000	8.0000
FIELD NO	1	2	3	4	5	6	7	8	9	10

X- 0 STAND ENGINE P-743- TIME 1131 DATE 09/12/77 P&WA ENGINE TEST LOG - DATA SYSTEM CERTIFIED BY ISAP 3:3161

JT9D-7A AFTER 1000 HOURS BELLMOUTH TYPE 2 THUMBWHEELS 9 9 9 9 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0

FIELD NO	1	2	3	4	5	6	7	8	9	10
PARAMETER	TT7A B/M	TT7B B/M	TT7C B/M	TT7D B/M	TT7E B/M	TT7F B/M				
CARD 72	1863.4688	1835.7153	1806.9888	992.6866	1884.1869	1879.7478	0.0000	0.0000	0.0000	0.0000
PARAMETER	PCL FAN	PCL FAN	PCL FAN	PCL FAN	PCL FAN	PCL FAN	PCL FAN	PCL FAN		
CARD 79	-1.8967	-8.6389•	-1.9865	-2.1263	-1.7869	-1.9965	-2.1463	-2.1863	0.0000	0.0000
PARAMETER	PCL TP	PCL TP	PCL TP	PCL TP						
CARD 80	-1.5673	-2.1463	-1.1488	-2.3168	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000•
PARAMETER	SP GR 1		SP GR 2		SP GR 3		SP GR 4		SP GR 5	
CARD 86	2523.8996	0.7979	2523.8996	0.7979	2523.8996	0.7979	2523.1997	0.7978	2523.8996	0.7979
PARAMETER	SG T FOR	SG T AFT	SUB AM T	T BAROM						
CARD 87	82.8246	82.5122	72.9372	124.9856	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
PARAMETER					PT3C EVC		PS3C EVC			
CARD 90	0.0000	0.0000	0.0000	0.0000	19.9688	0.0000	11.6388	0.0000	0.0000	0.0000
PARAMETER	REF 1	REF 2	REF 3	REF 4	REF 5	REF 86	REF 13	REF 14	REF 9	REF 10
CARD 92	62.8428•	62.8045•	66.7838•	66.3128•	62.6852•	62.8046•	63.2926•	63.1859•	71.8627•	72.5921•
PARAMETER	FNA-1	FNB-1	FNA-2	FNB-2	FNA-3	FNB-3	FNA-4	FNB-4	FNA-5	FNB-5
CARD 93	7654.8986	7654.4998	7657.4998	7657.8994	7658.8986	7658.3994	7647.3994	7647.8992	7651.6992	7652.8986
PARAMETER	N1-1	N1-2	N1-3	N1-4	N1-5	N2-1	N2-2	N2-3	N2-4	N2-5
CARD 94	3483.3891	3484.7432	3483.8386	3481.7437	3481.3525	7459.9998	7457.7988	7456.1992	7461.3994	7468.3994
PARAMETER										CONF T
CARD 95	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	72.6281•
PARAMETER	C1X11CPS	C0X1 CPG	C0X12CPS	C0X1 CPG	C0X13CPS	C0X1 CPG	C0X14CPS	C0X1 CPG	C0X15CPS	C0X1 CPG
CARD 96	858.1998	1148.6948	858.3999	1148.6953	858.4999	1148.6958	856.9999	1148.6917	857.4999	1148.6929
PARAMETER	C0X21CPS	C0X2 CPG	C0X22CPS	C0X2 CPG	C0X23CPS	C0X2 CPG	C0X24CPS	C0X2 CPG	C0X25CPS	C0X2 CPG
CARD 97	822.8999	1181.3987	822.2999	1181.3984	822.3999	1181.3984	828.9999	1181.3992	821.3999	1181.3989
PARAMETER						MUX 0	MUX 1	MUX 2		
CARD 99	0.0000	0.0000	0.0000	0.0000	0.0000	2.4995•	2.4998•	2.5005•	0.0000	0.0000•

FIELD NO	1	2	3	4	5	6	7	8	9	10

APPENDIX G

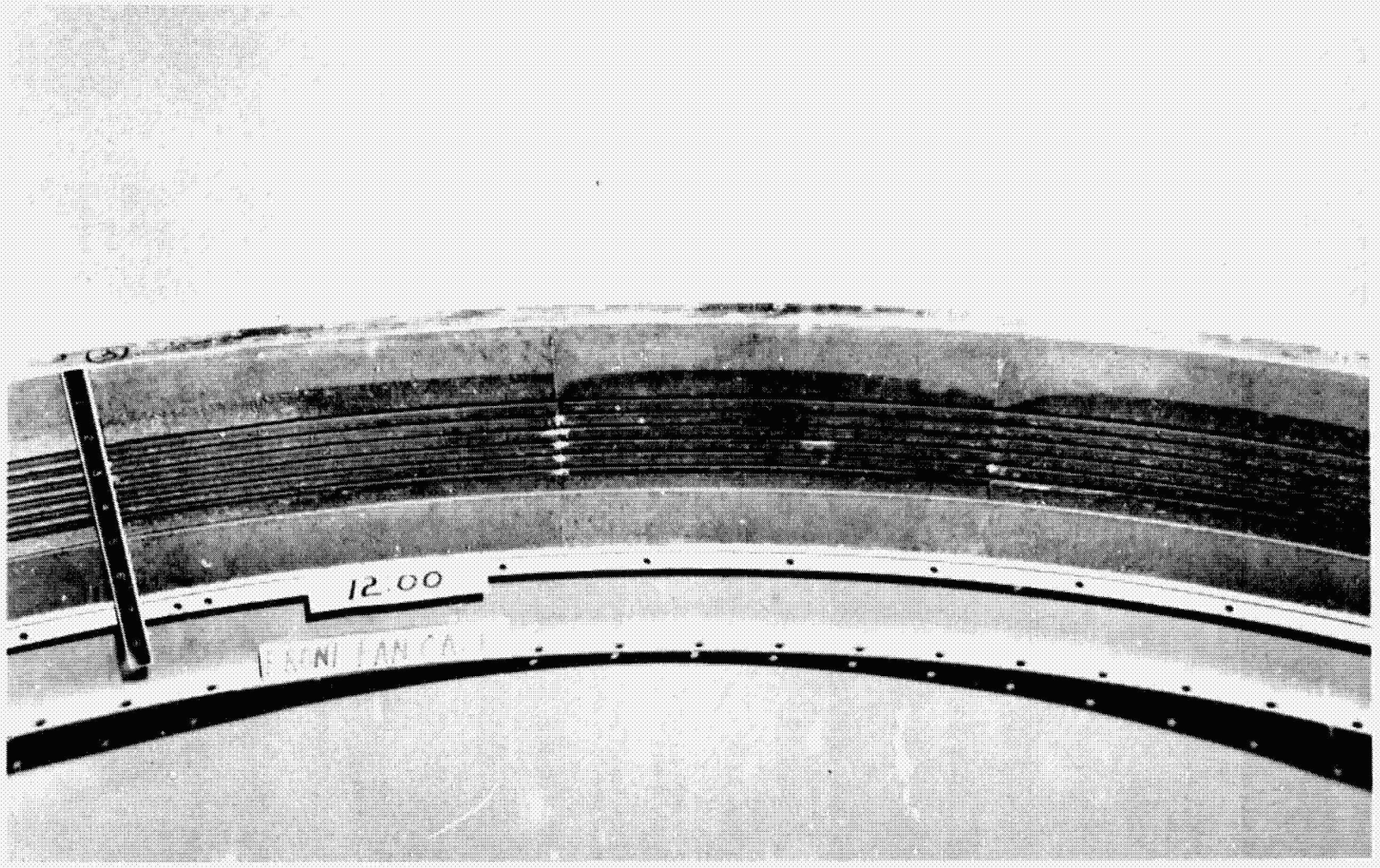
ANALYTICAL TEARDOWN PHOTOGRAPHS

Short-Term Deterioration Engine,
Serial No. 695743, After 1081
Flight Hours and 141 Flight Cycles

FAN MODULE

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JT9D Diagnostics Short Term Deteriorated Engine, P-695743, 1081 Hours, 141 Cycles Contract NAS3-20632 Maximum Rub Area
77-444-0254-A



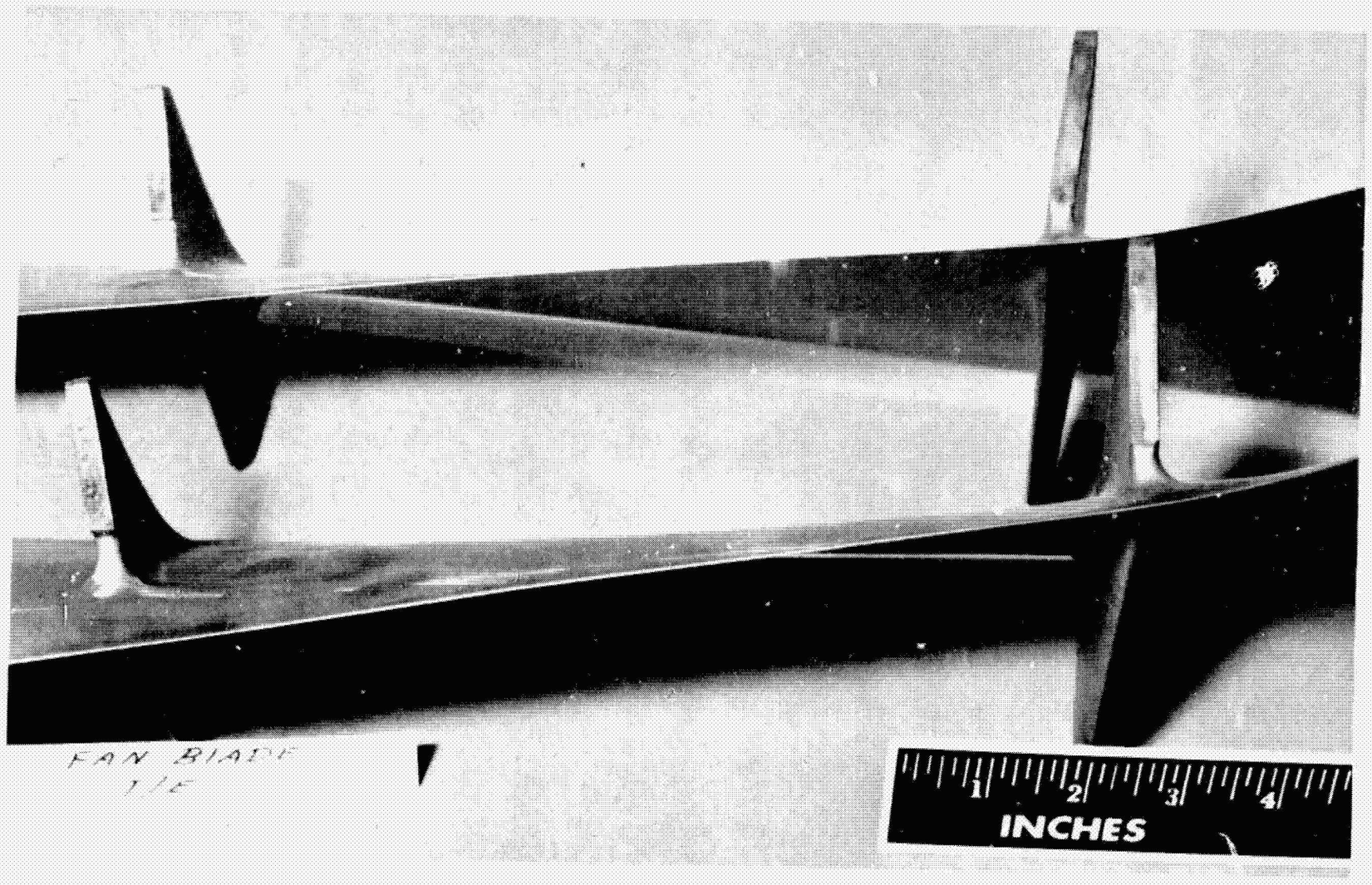
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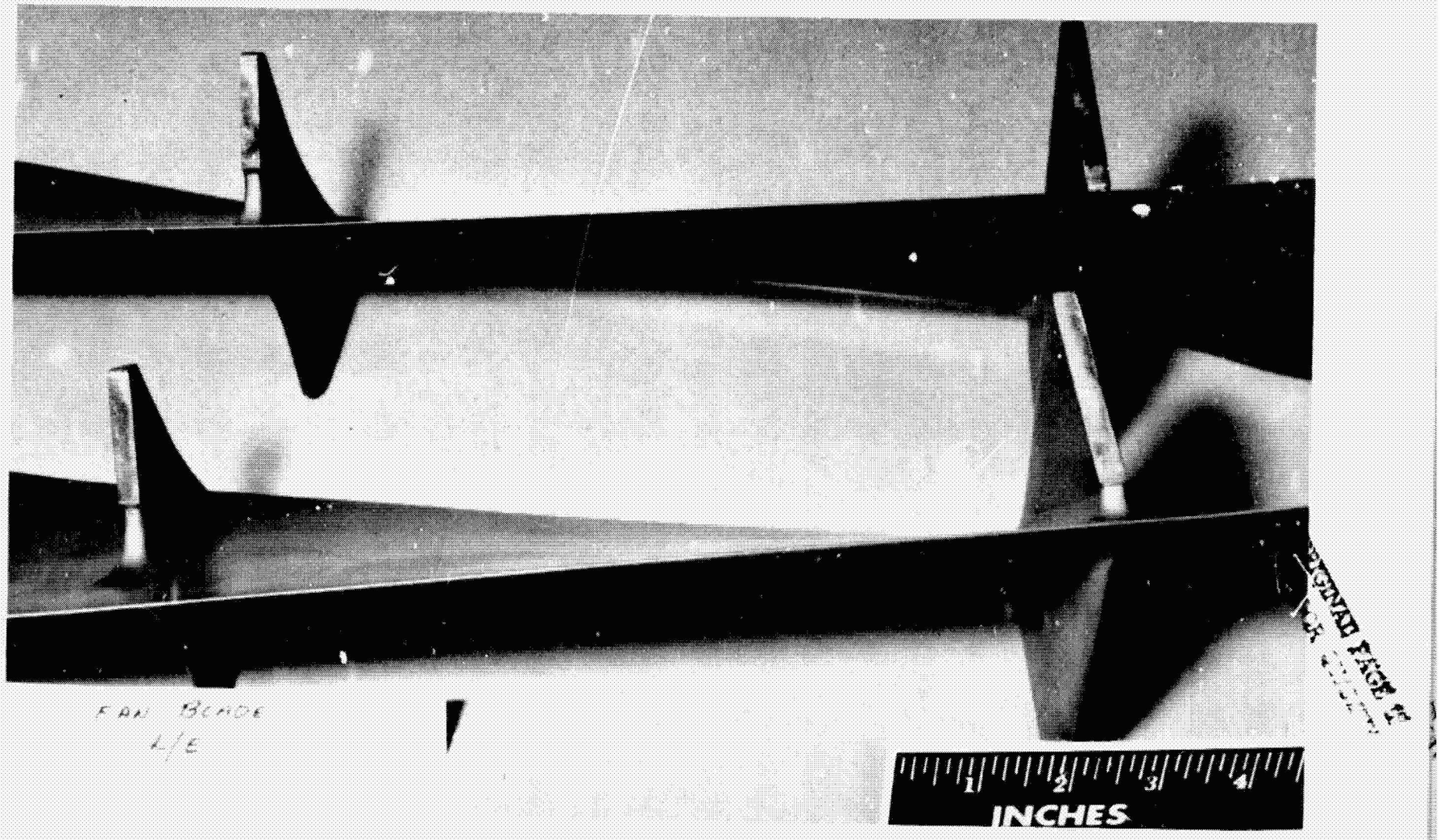
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77-444-0254-C



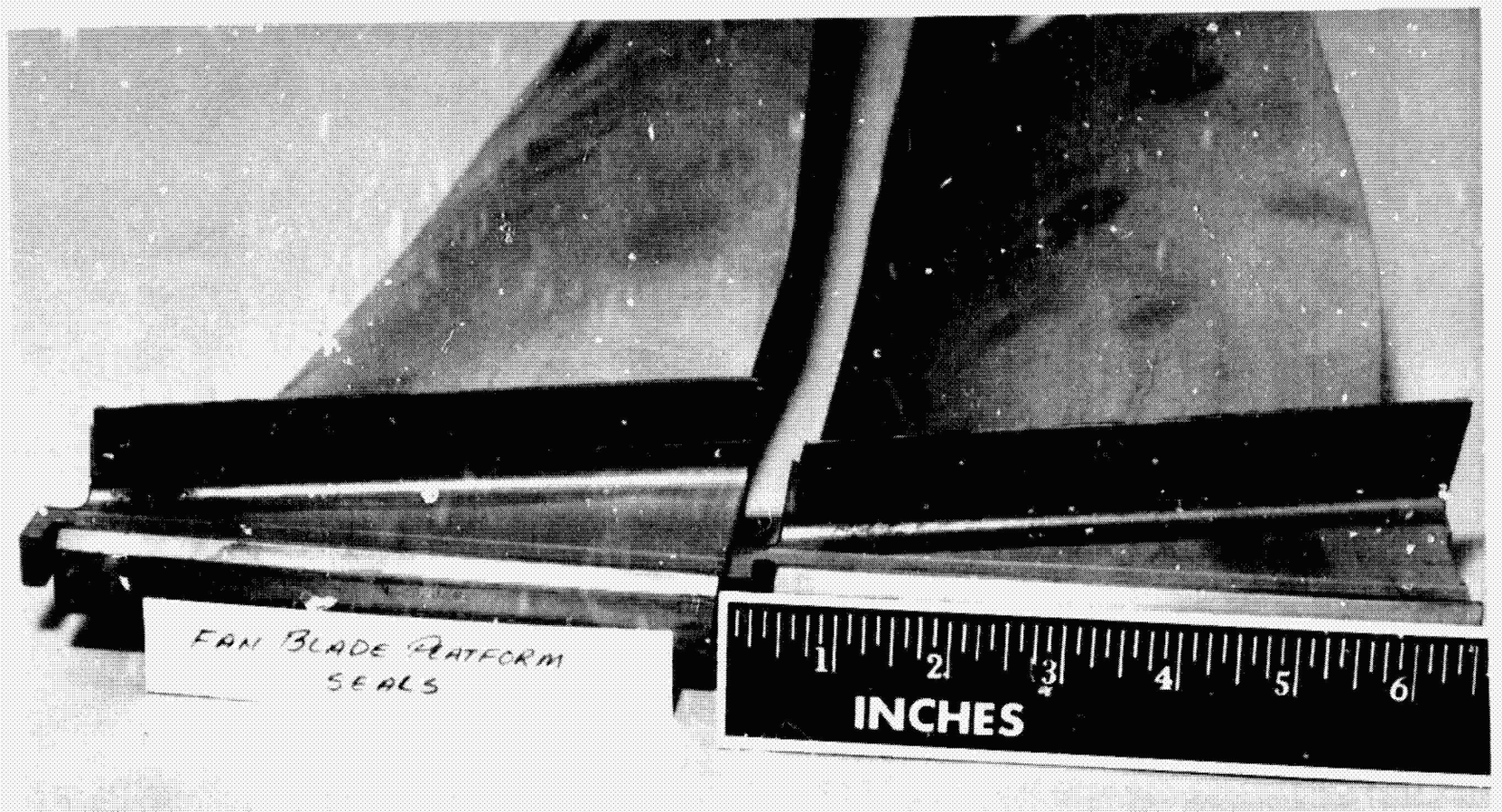
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77-444-0254-AB



JT9D Diagnostics Short Term Deteriorated Engine, P-695743, 1081Hours, 141 Cycles Contract NAS3-20632 Typical Shroud Condition

77-444-0254-AC



JT9D Diagnostics Short Term Deteriorated Engine, P-695743, 1081 Hours, 141 Cycles Contract NAS3-20632 Typical Seal Condition

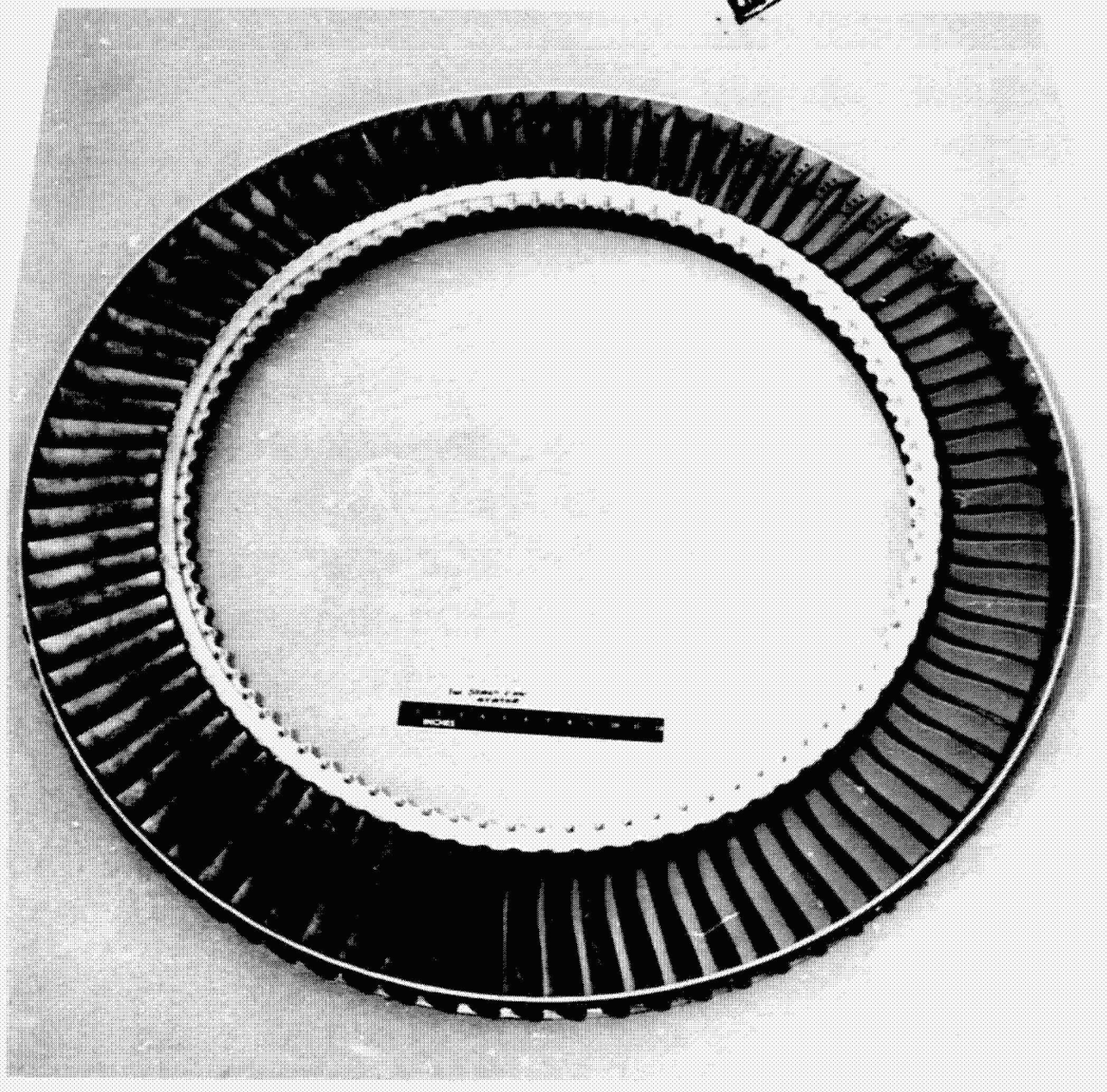
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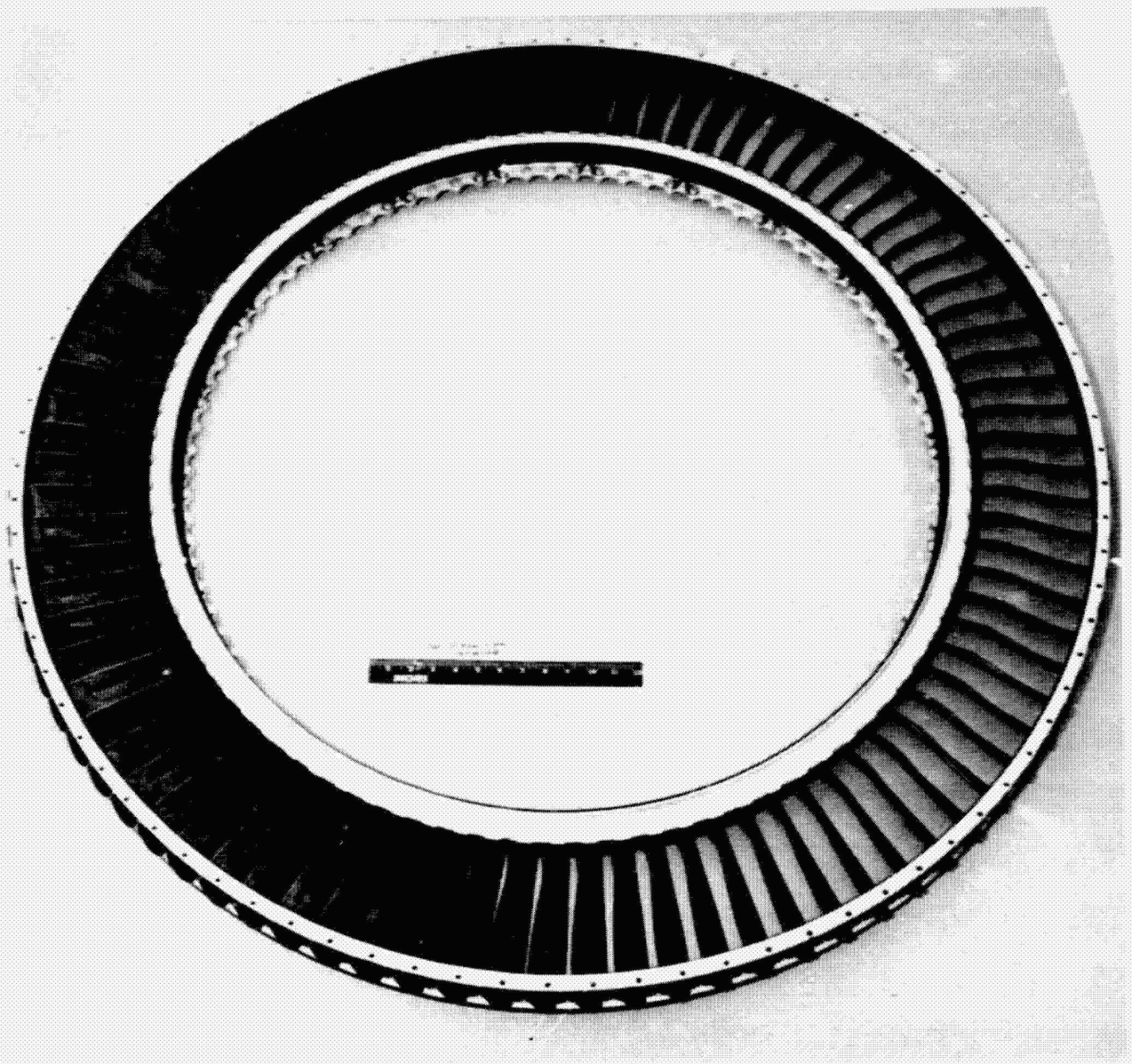
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LOW-PRESSURE COMPRESSOR MODULE

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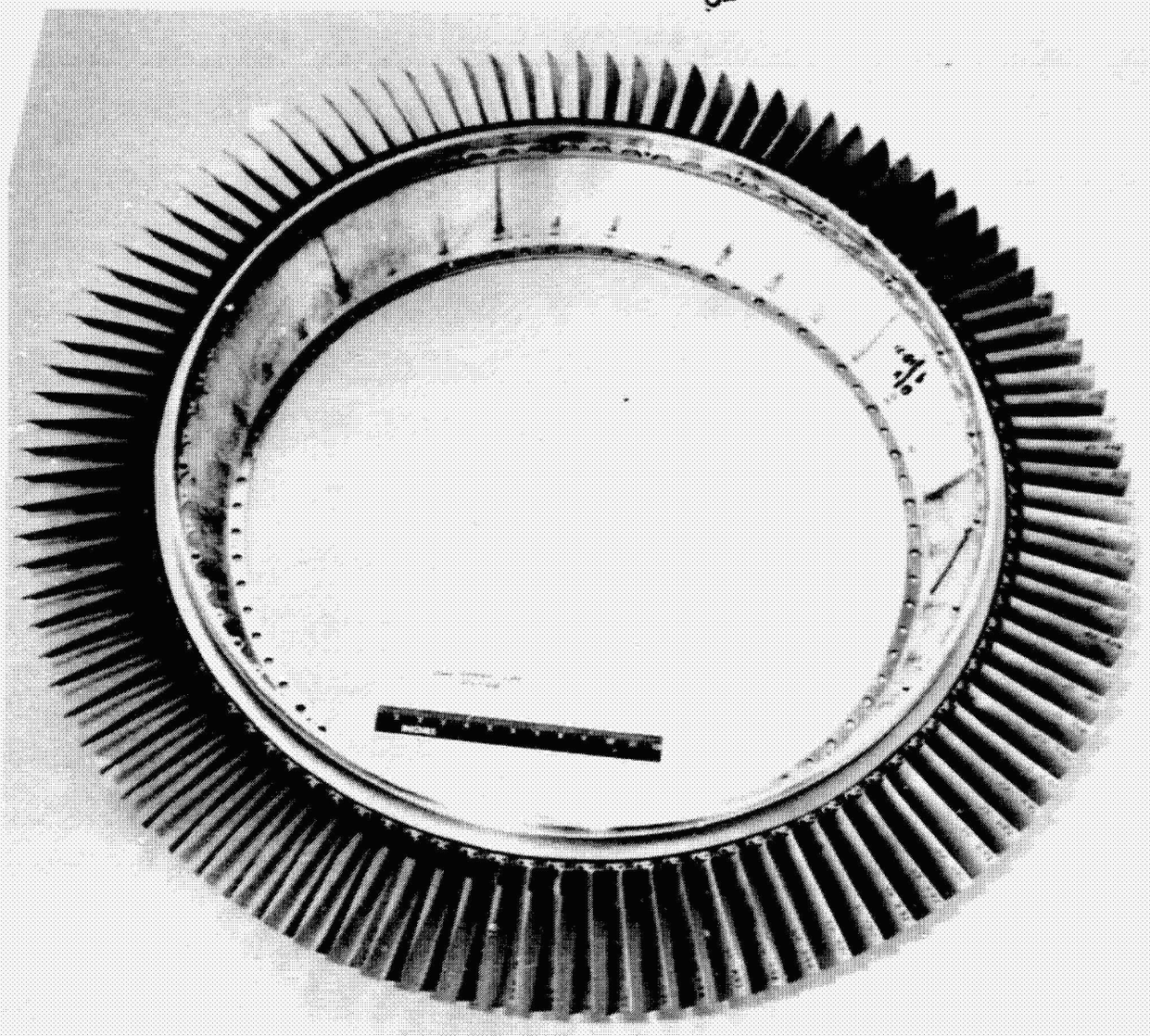
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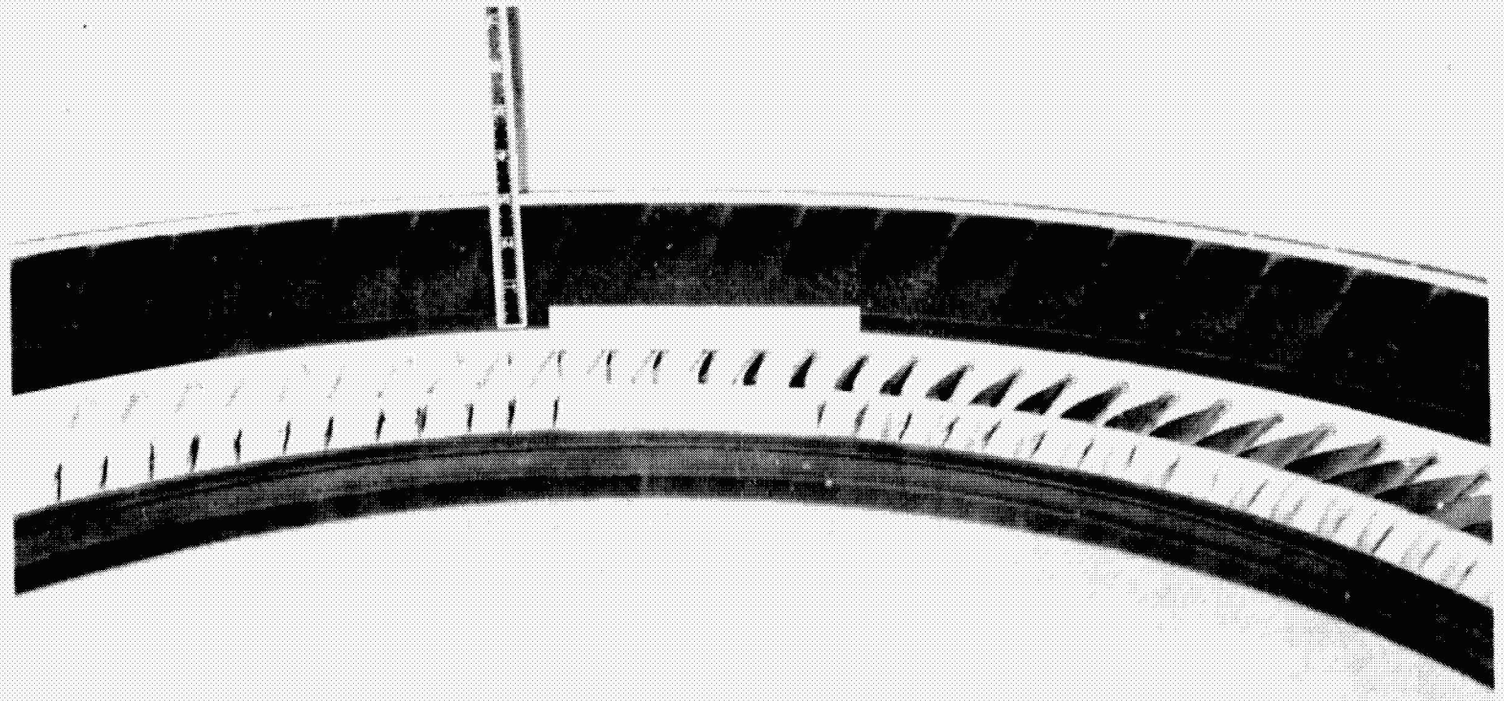
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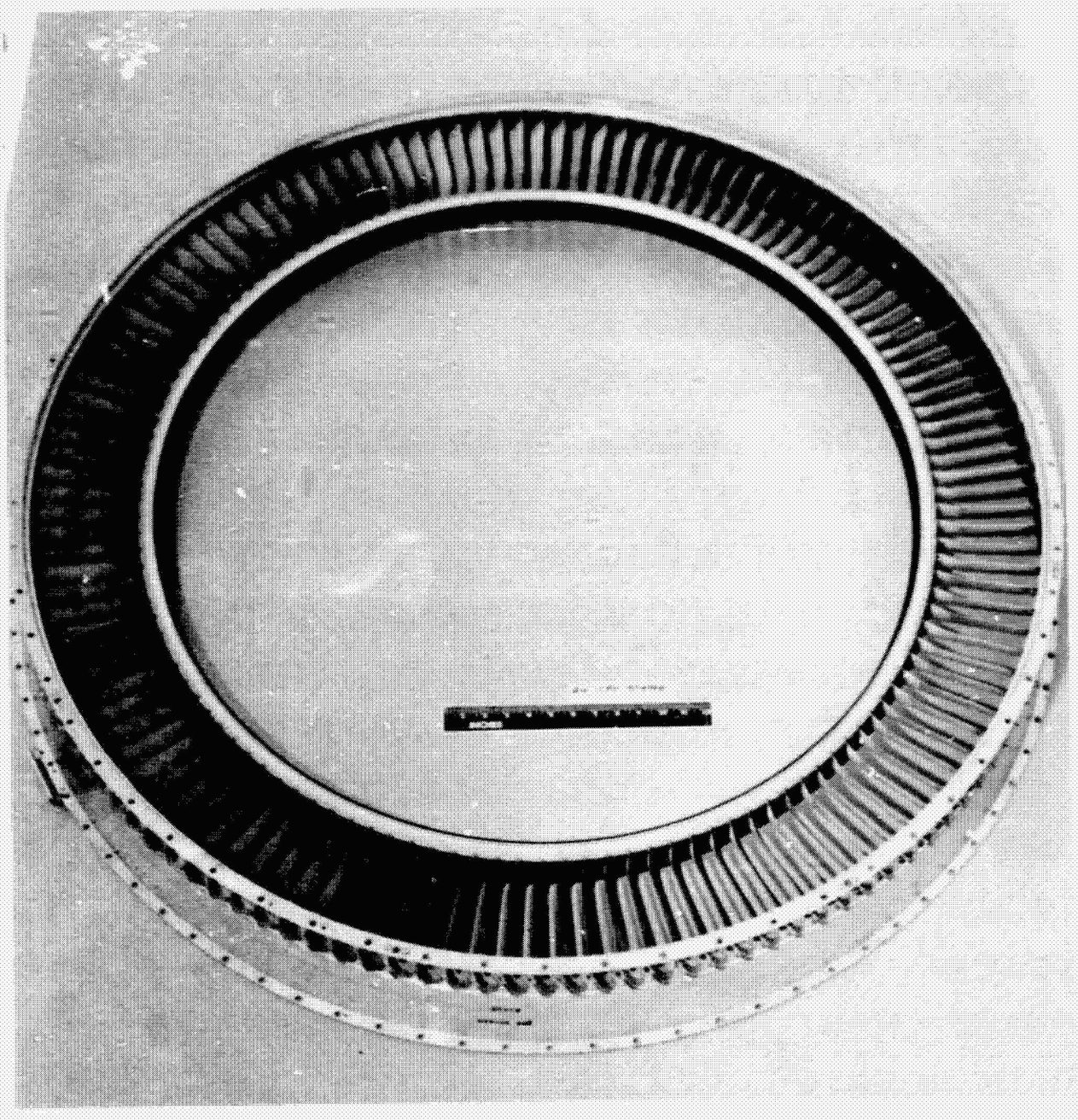


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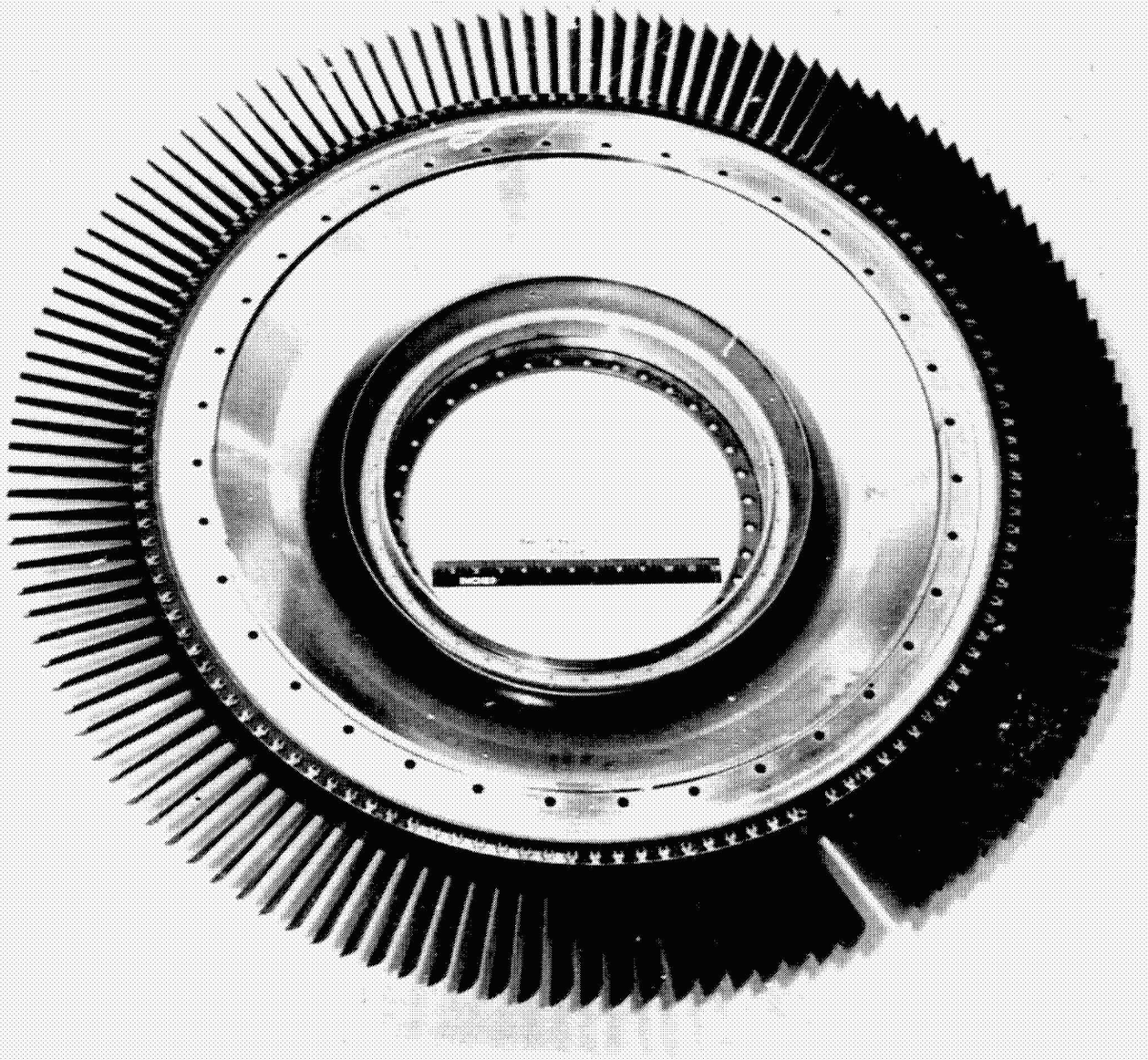


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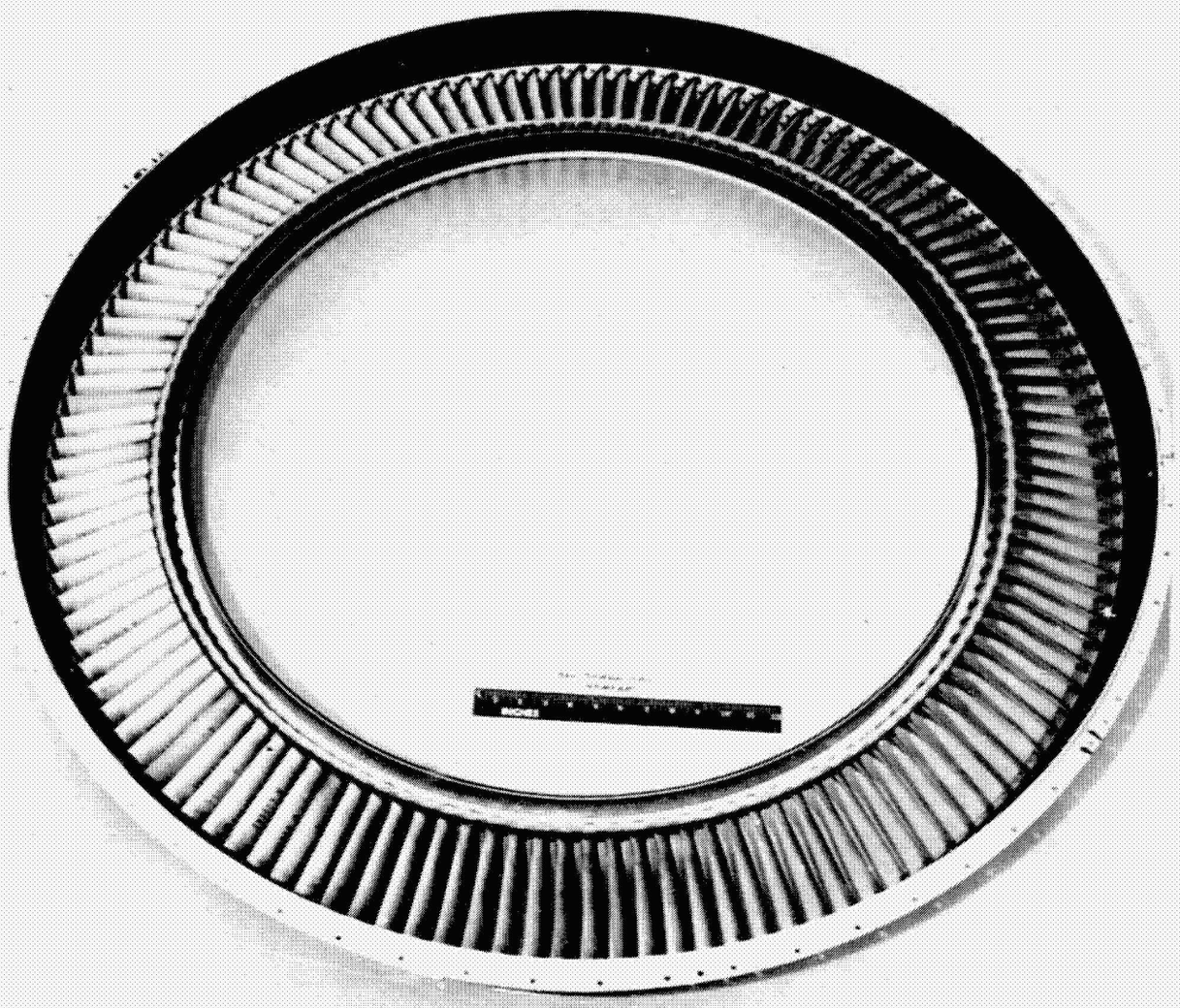
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77-444-0254-AK



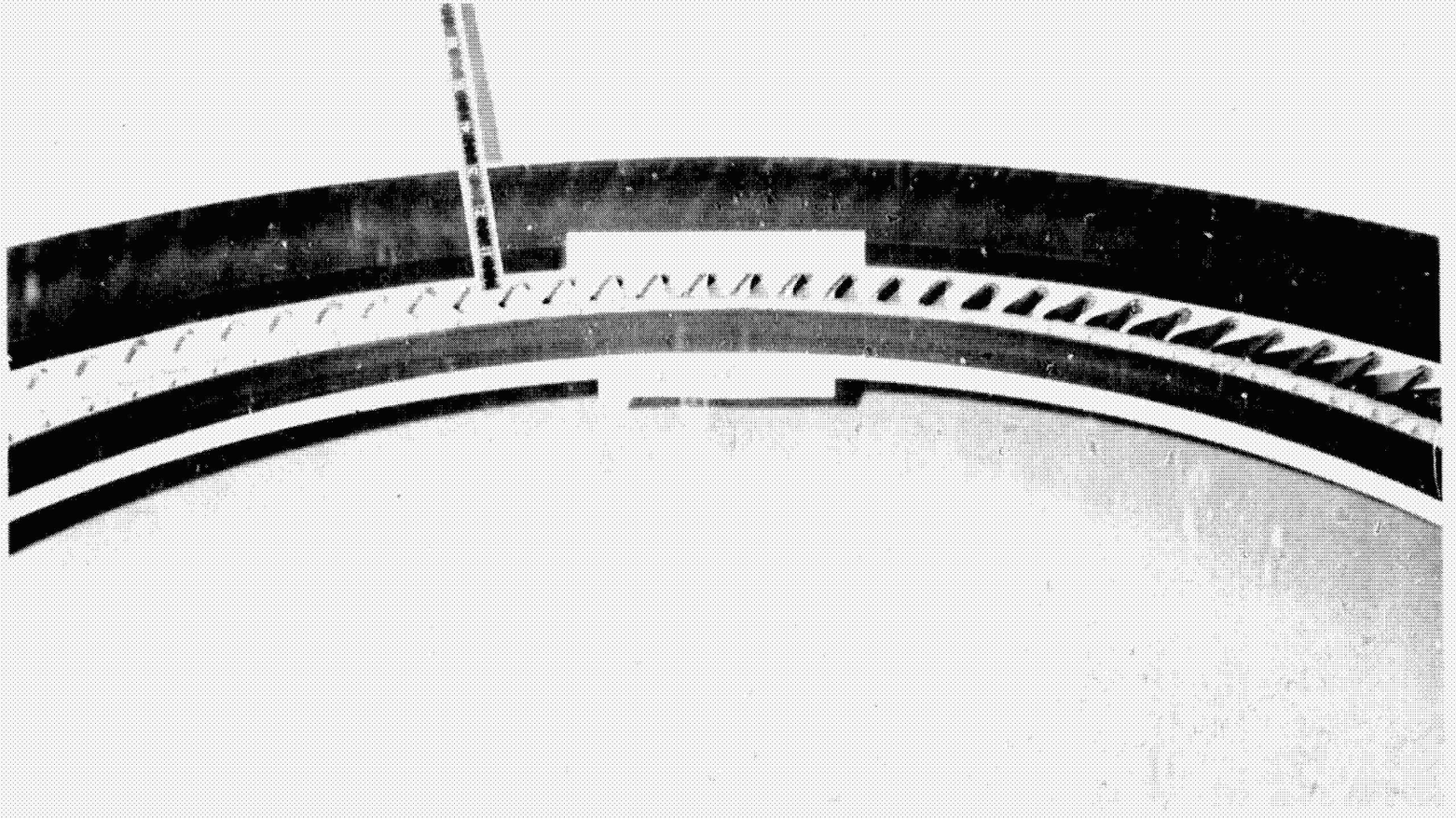
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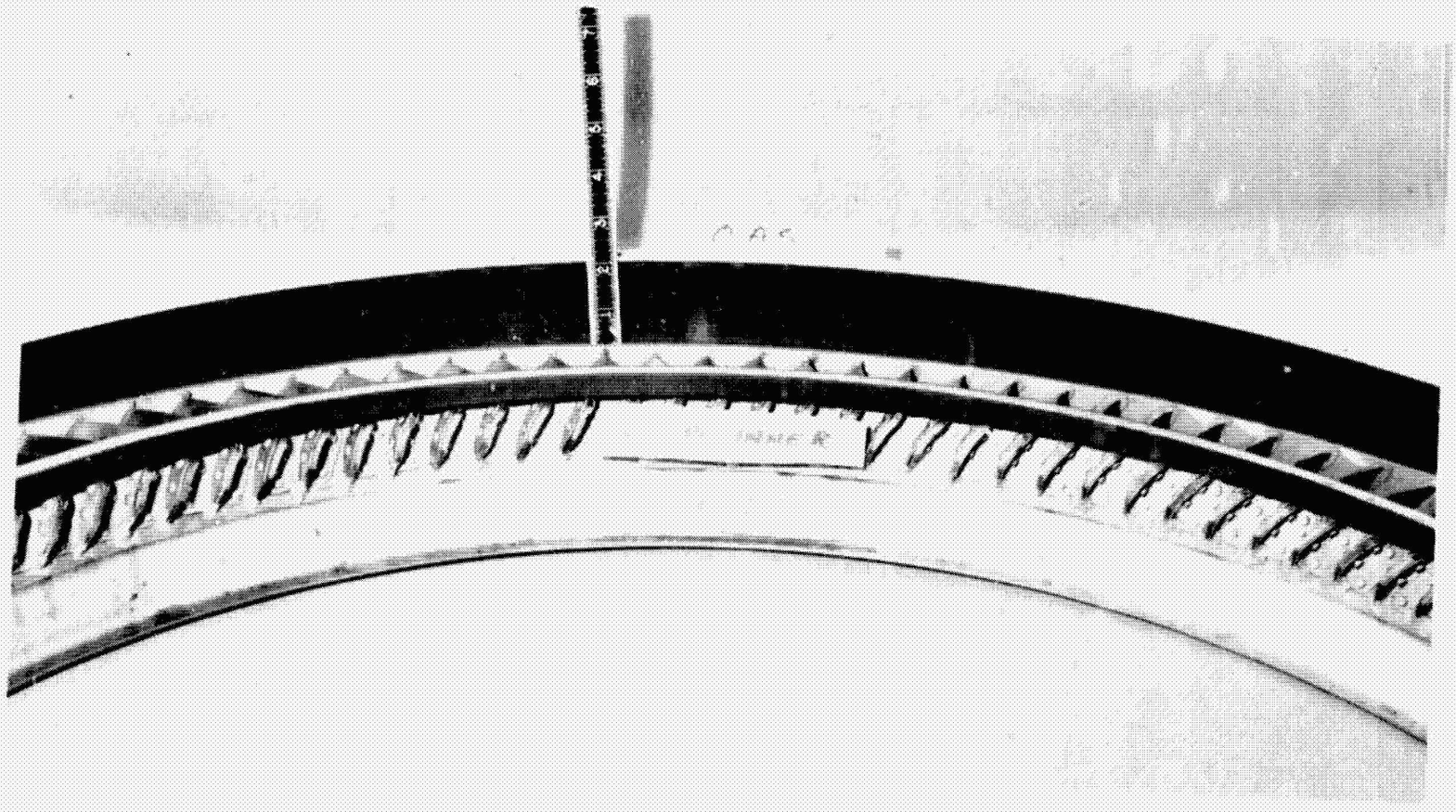


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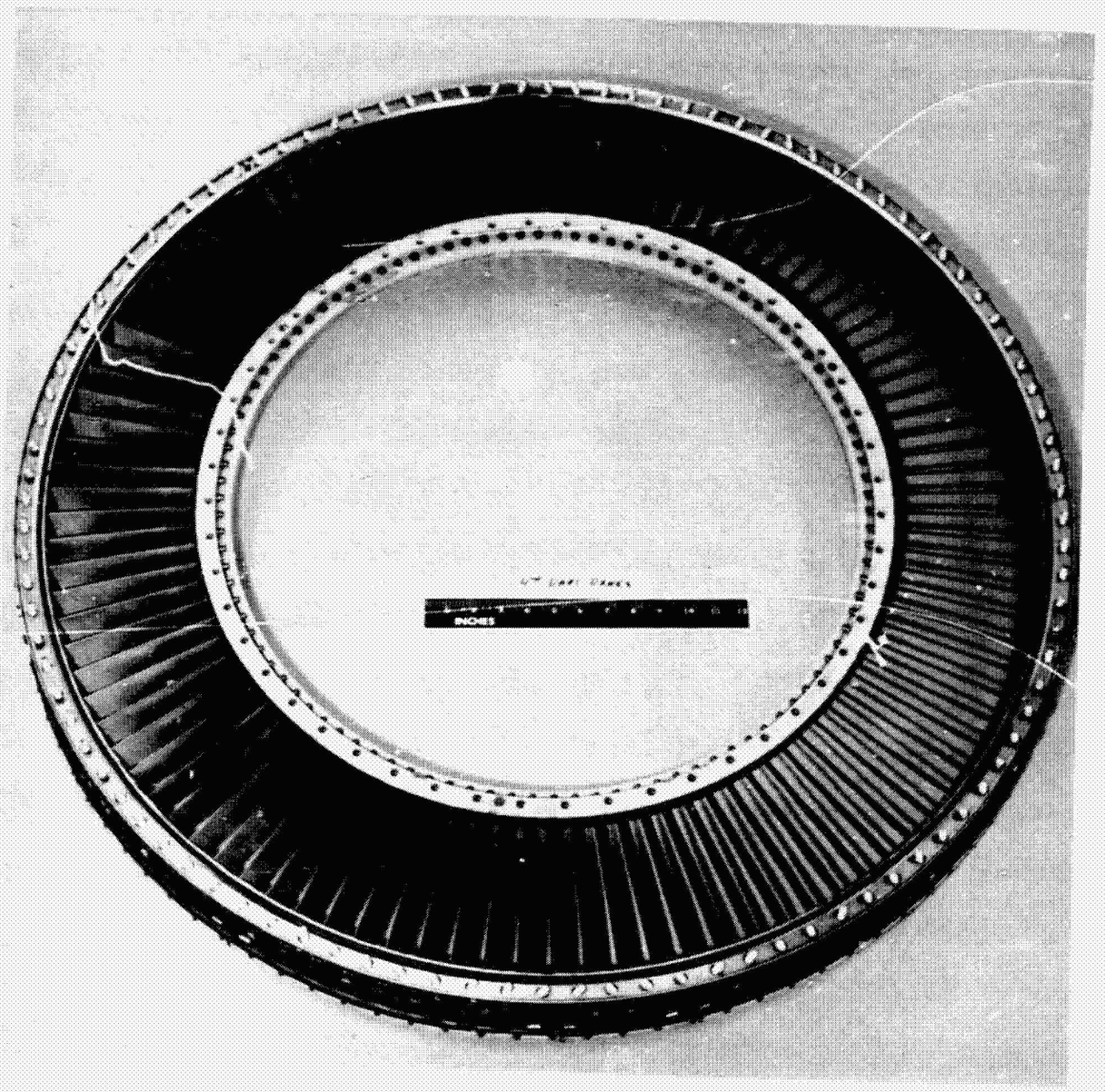


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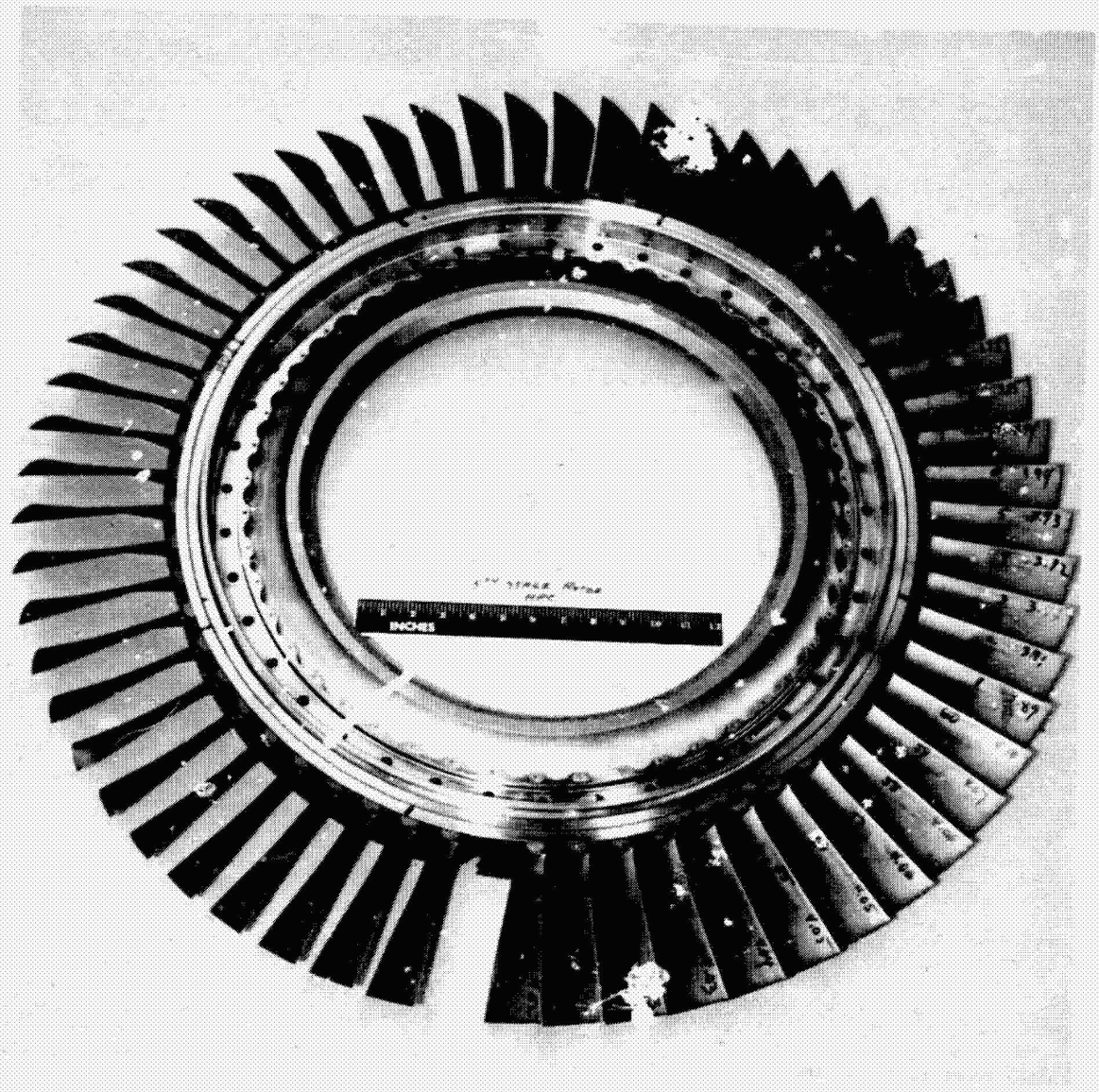
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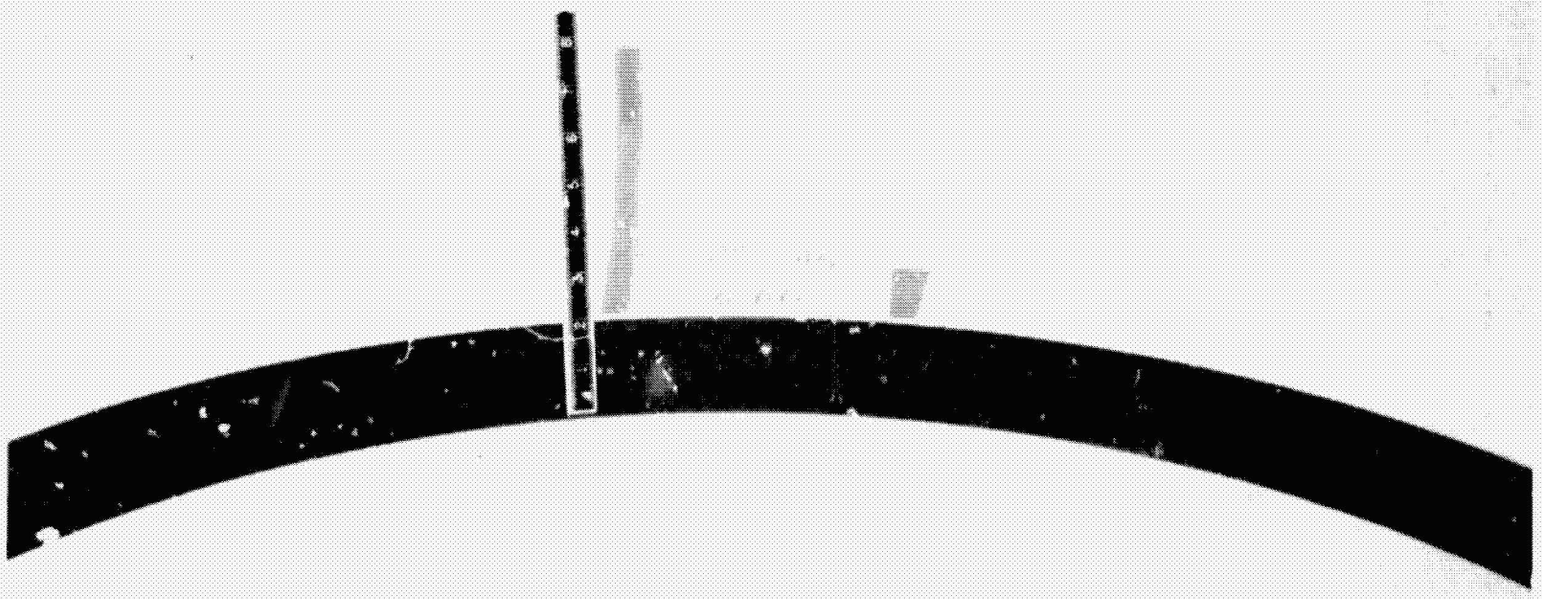
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HIGH-PRESSURE COMPRESSOR MODULE



JT9D Diagnostics Short Term Deteriorated Engine, P-695743, 1081 Hours, 141 Cycles Contract NAS3-20632 LE Condition

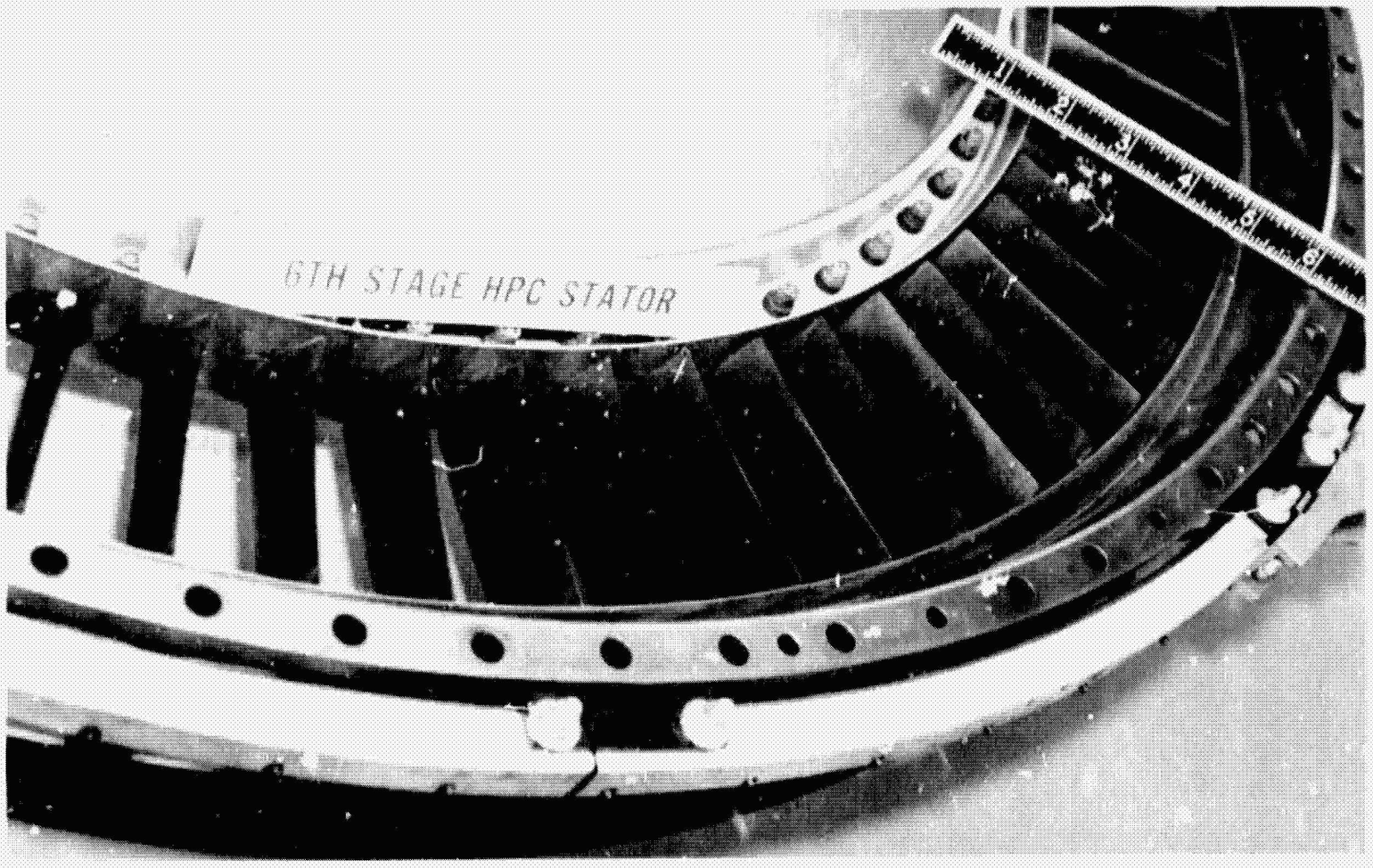
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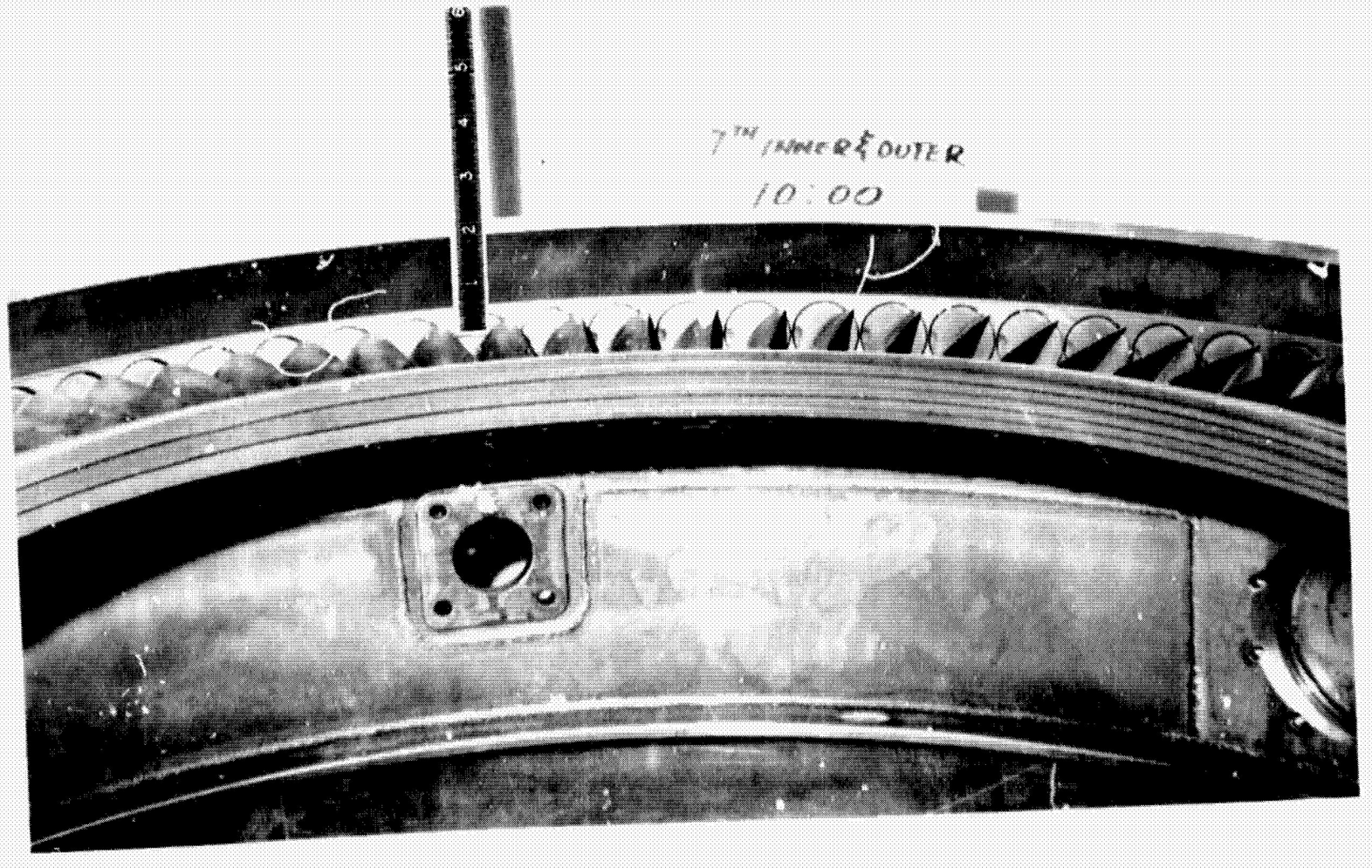
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77-444-0254-G

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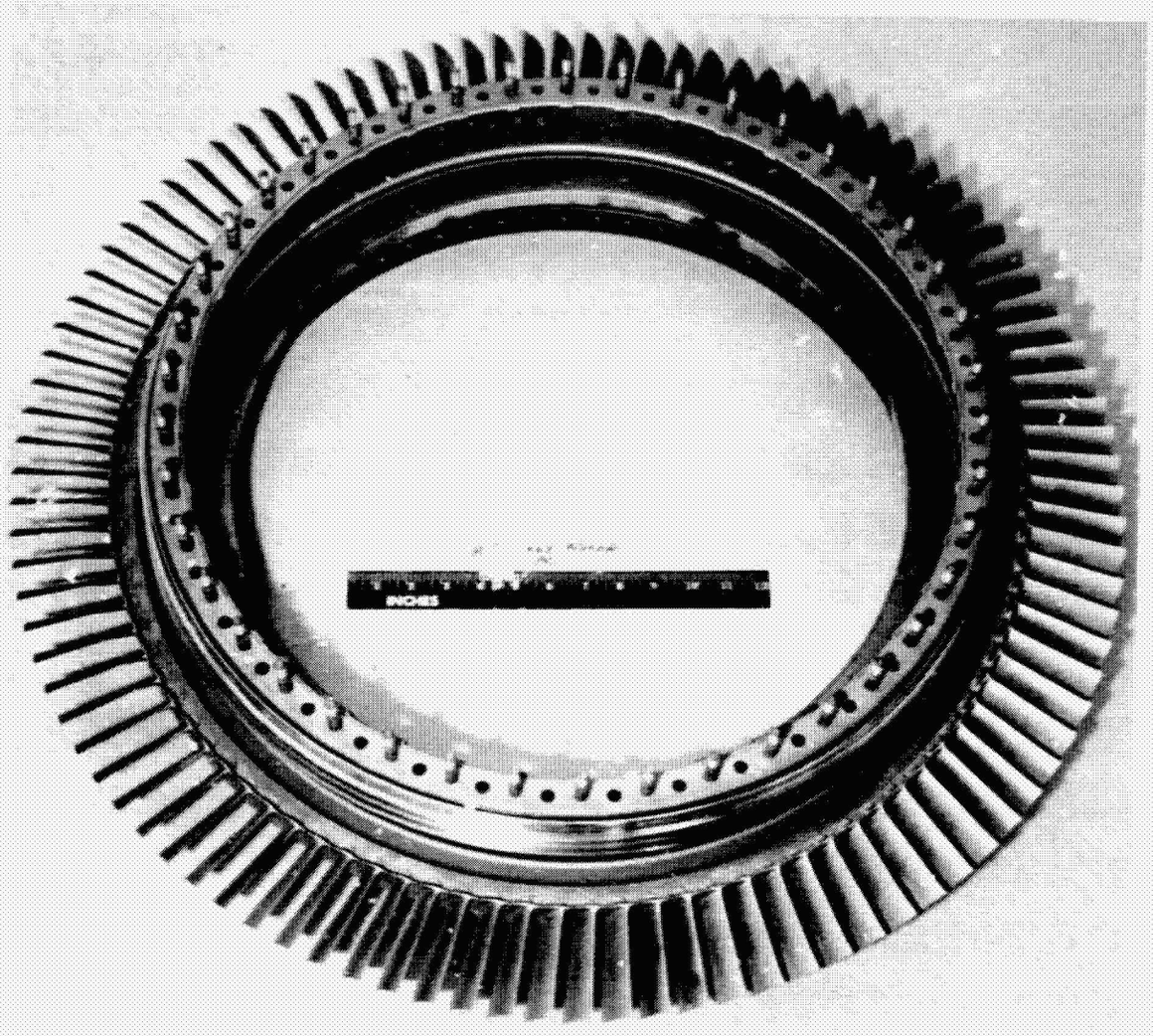
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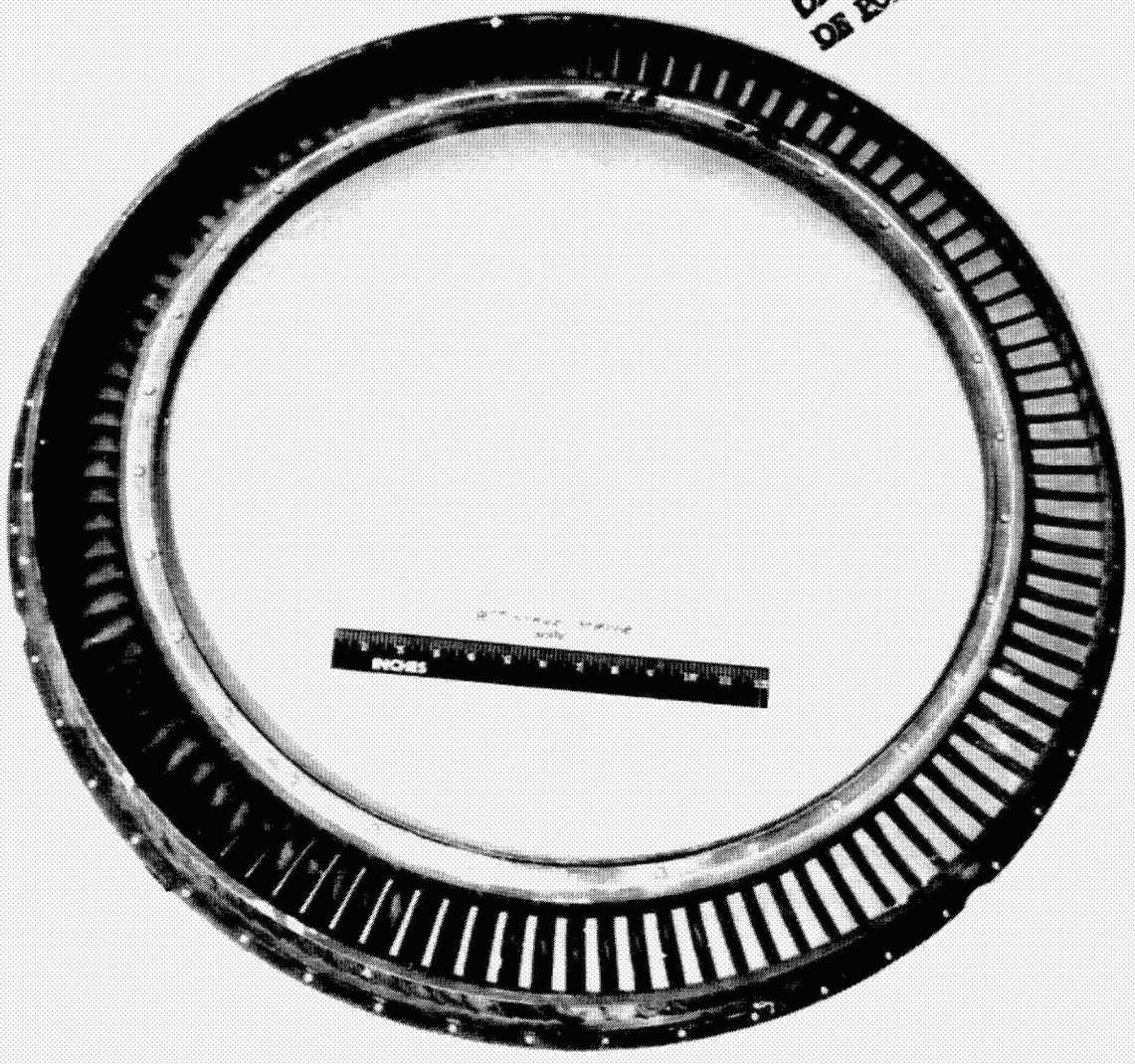
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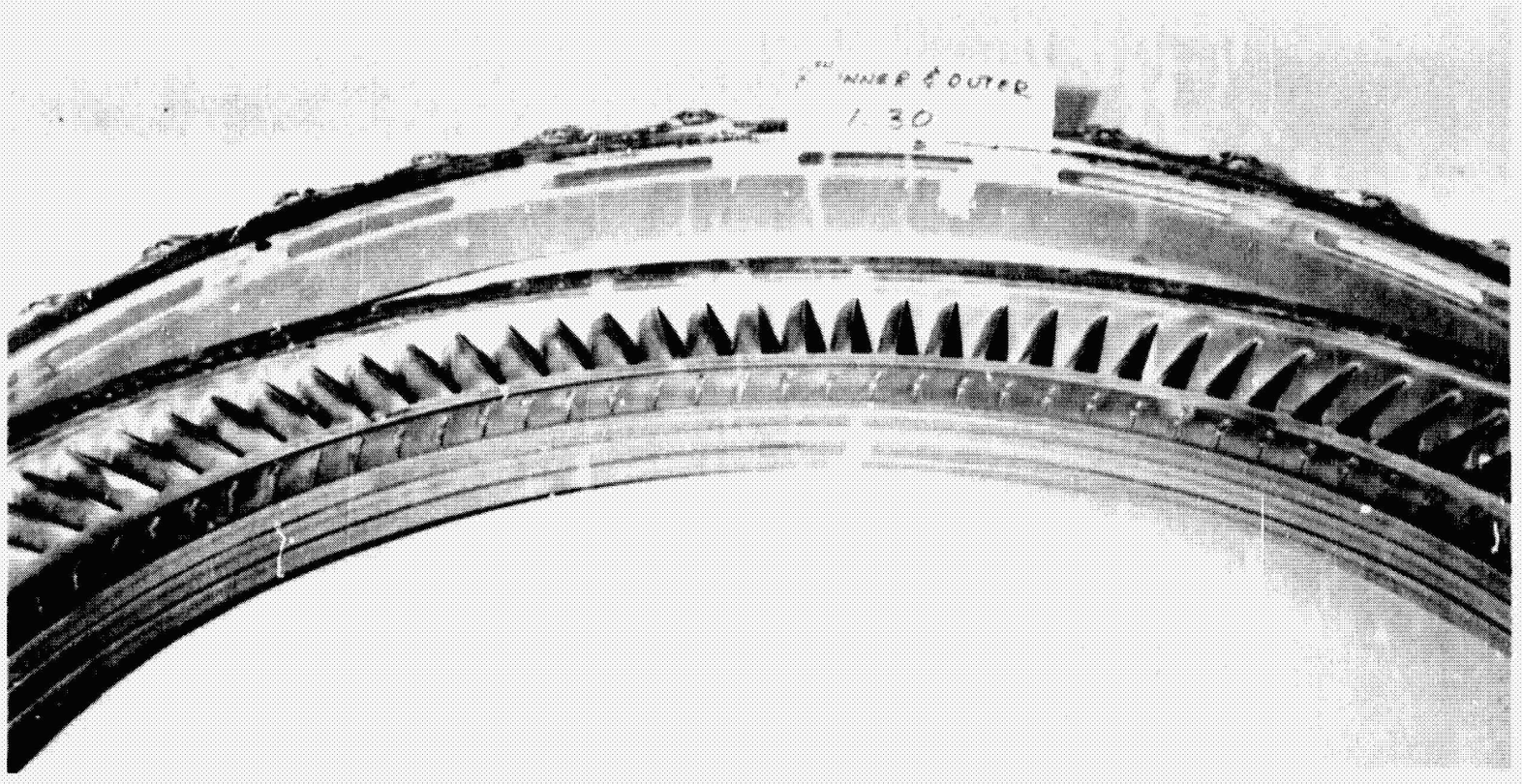
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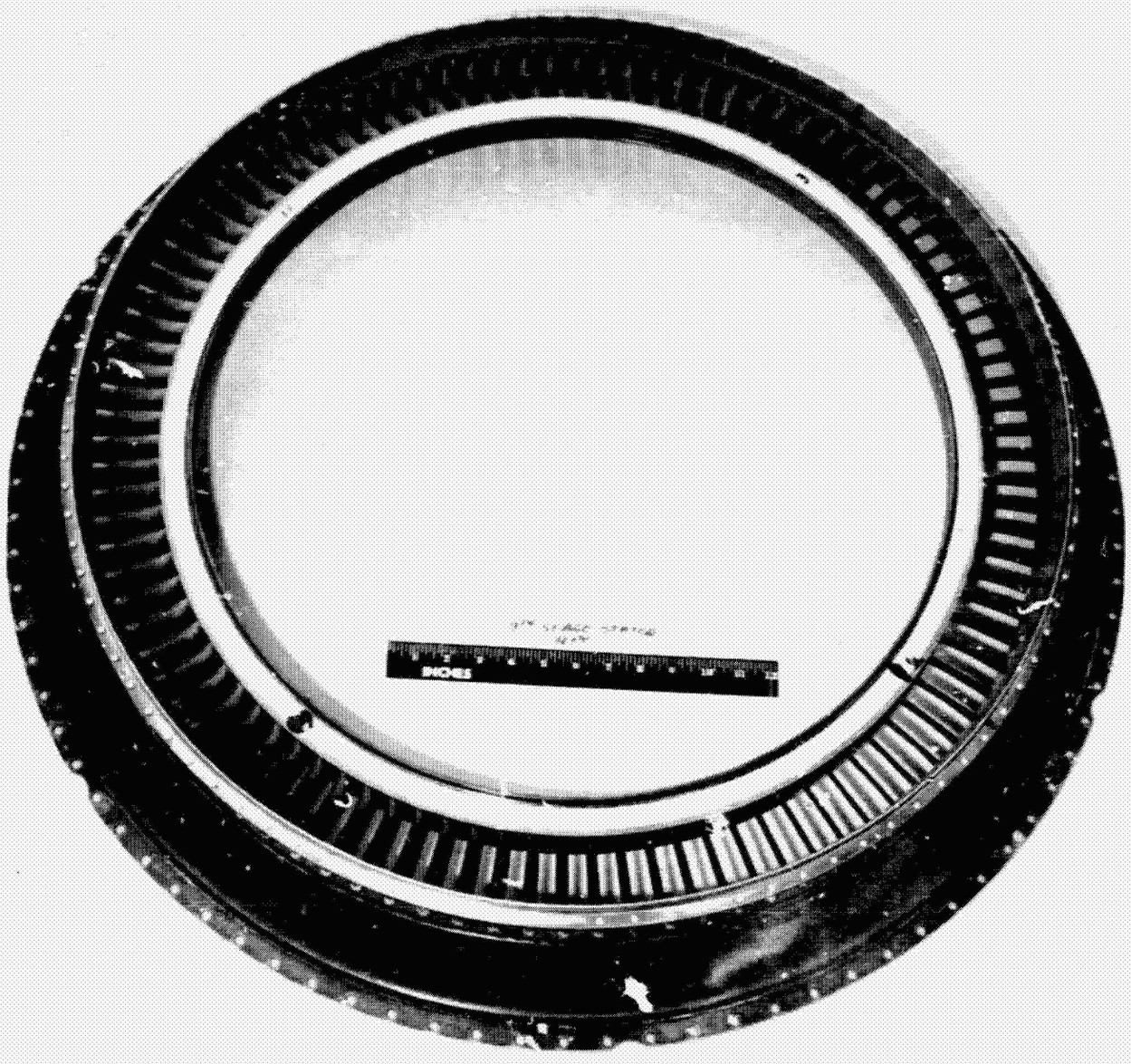


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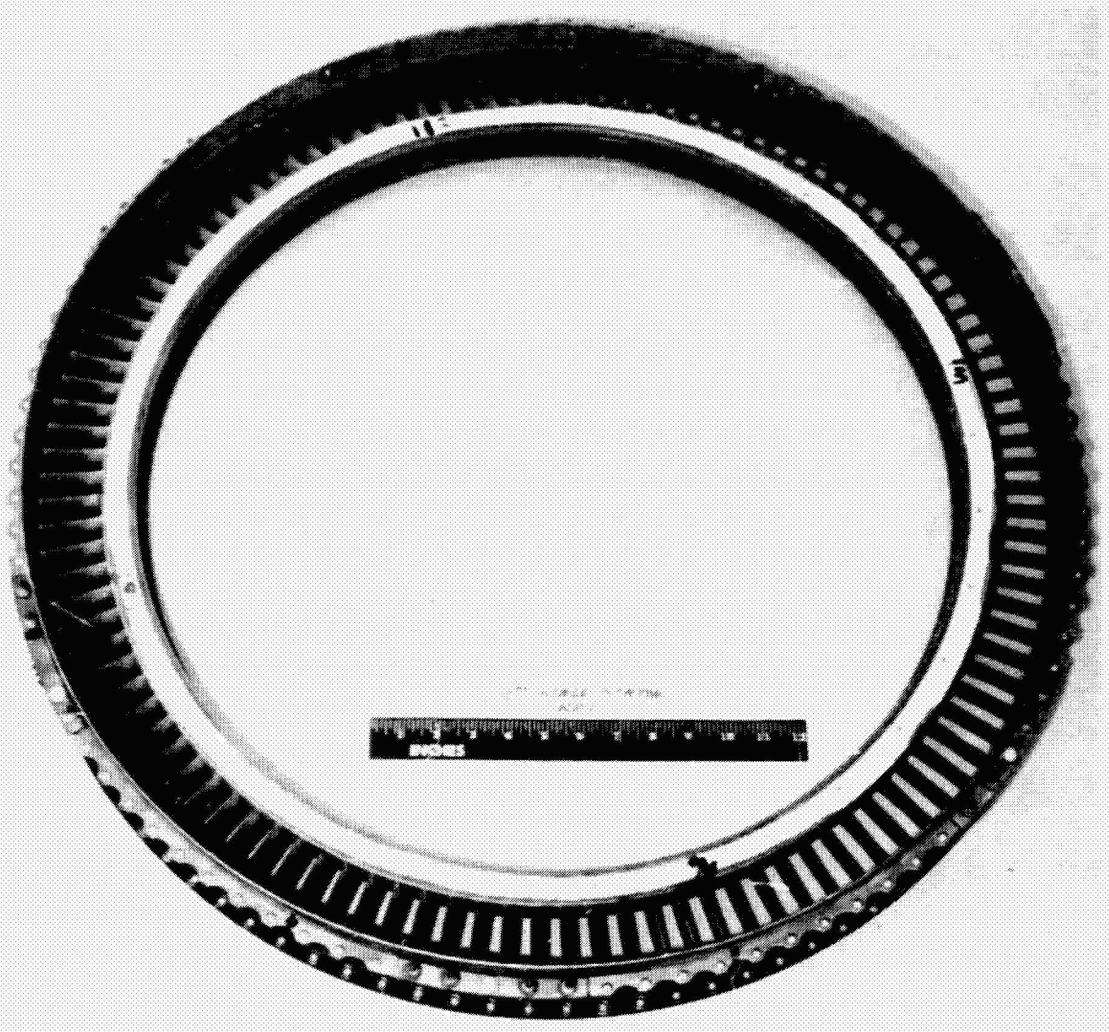


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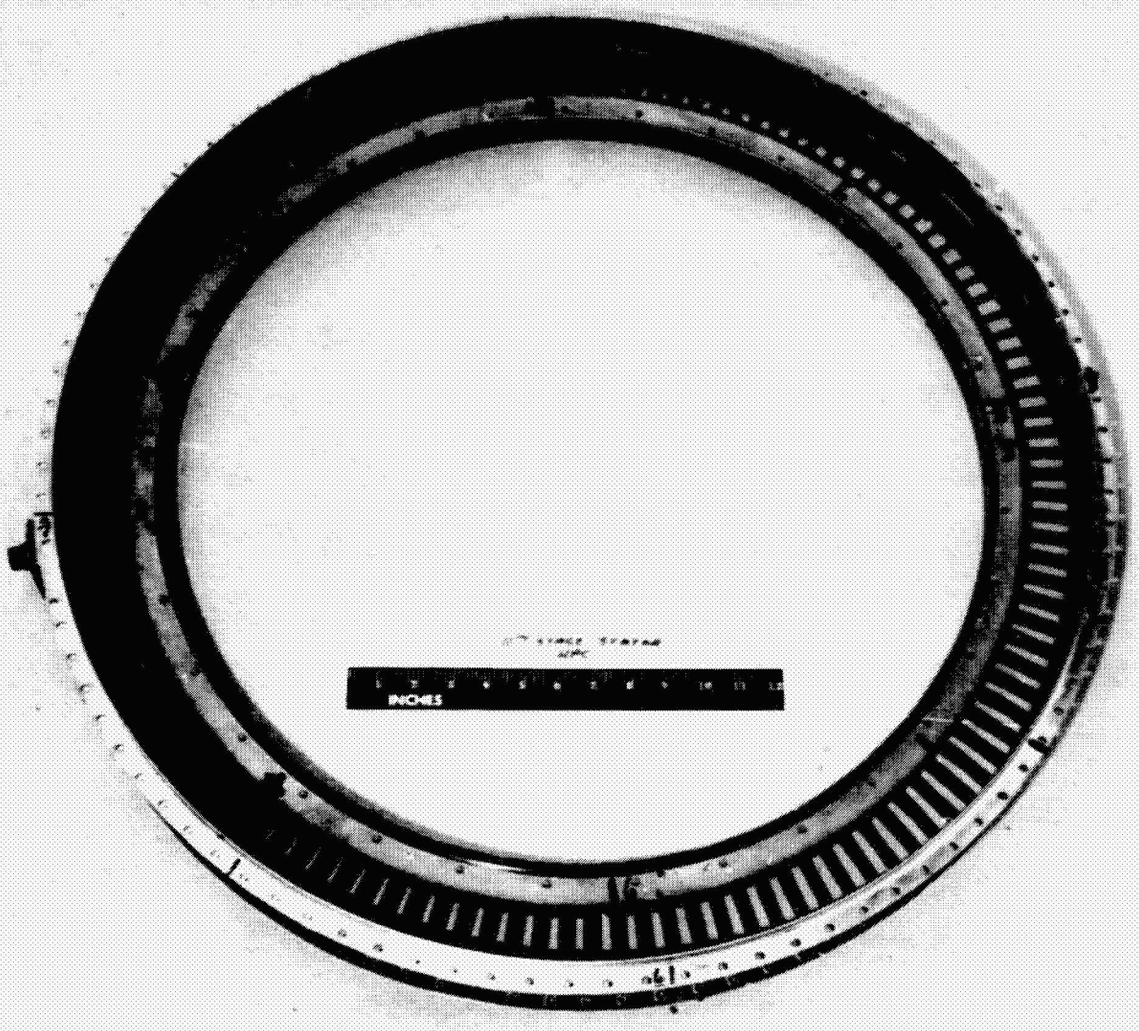


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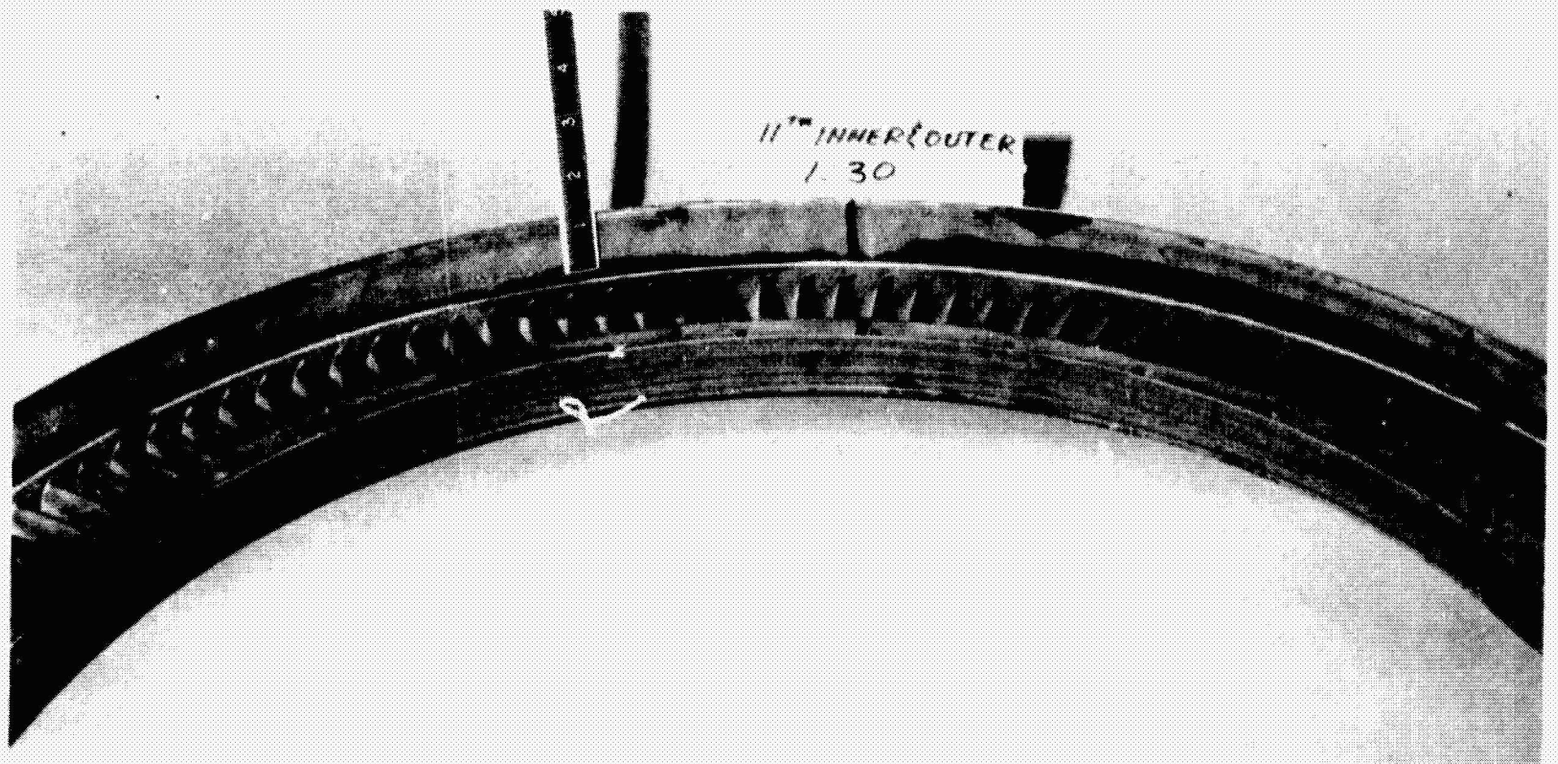
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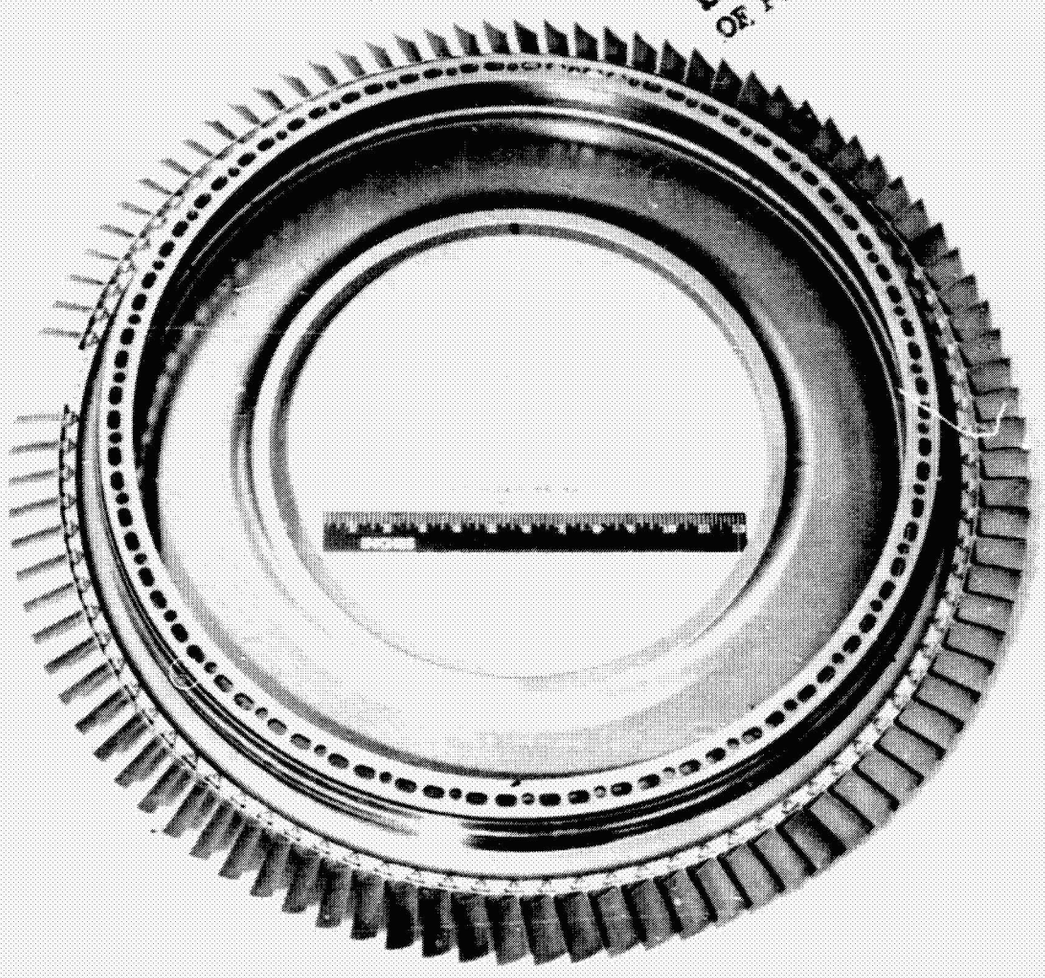
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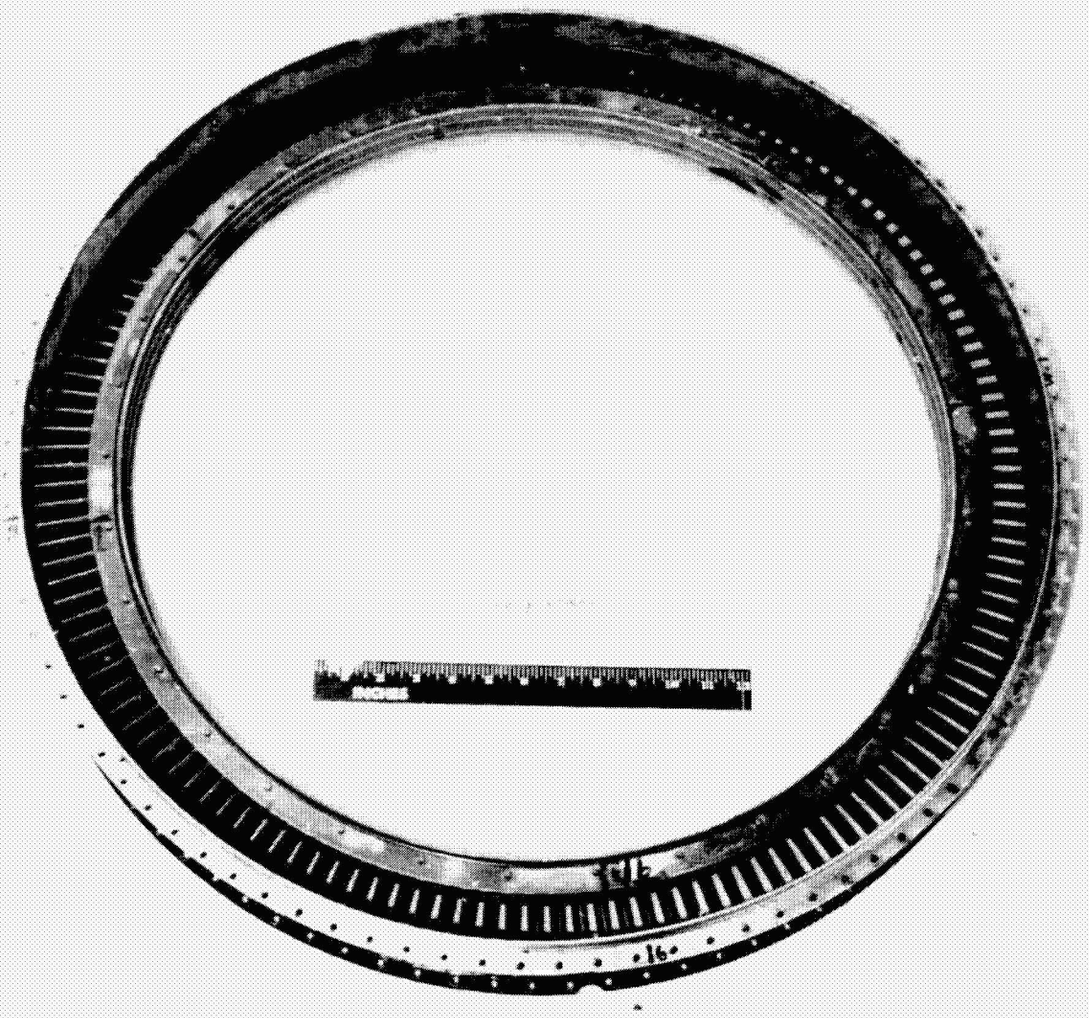
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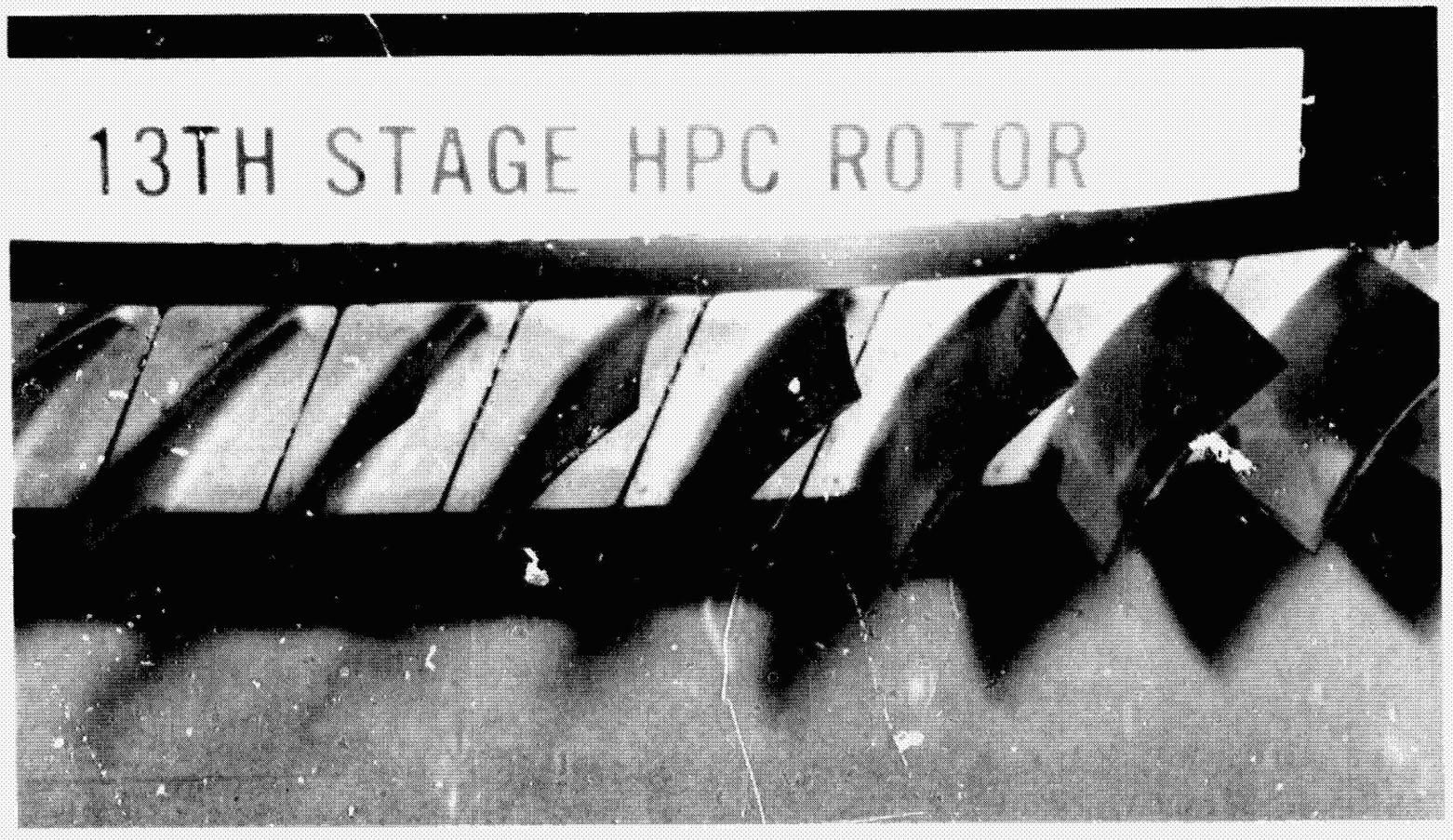
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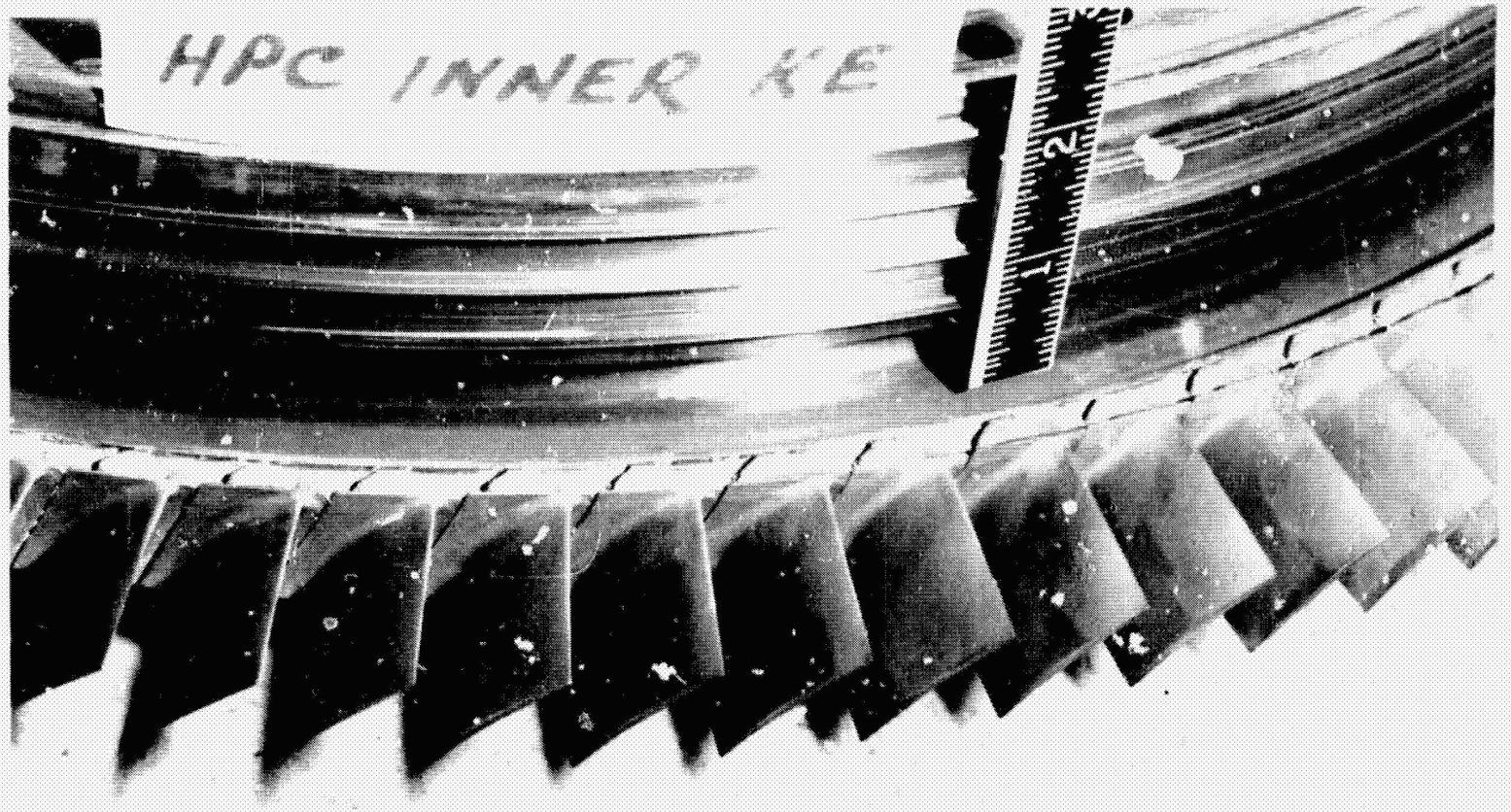
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JT9D Diagnostics short Term Deteriorated Engine P-695743, 1081 Hours, 141 Cycles Contract NAS3-20632 Seal Condition 77-444-0254-AS



JT9D Diagnostics Short Term Deteriorated Engine, P-695743, 1081 Hours, 147 Cycles Contract NAS3-20632 HPC Blade Tip Rub Indications 77-444-0254-L



JT9L [illegible]gnostics Short Term Deteriorated Engine, P-695743, 1081 Hours, 141 Cycles Contract NAS3-20632 HPC Blade & KE Condition 77-444-0254-Y

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JT9D Diagnostics Short Term Deteriorated Engine, P-695743, 1081 Hours, 141 Cycles Contract NAS3-20632 TE Condition

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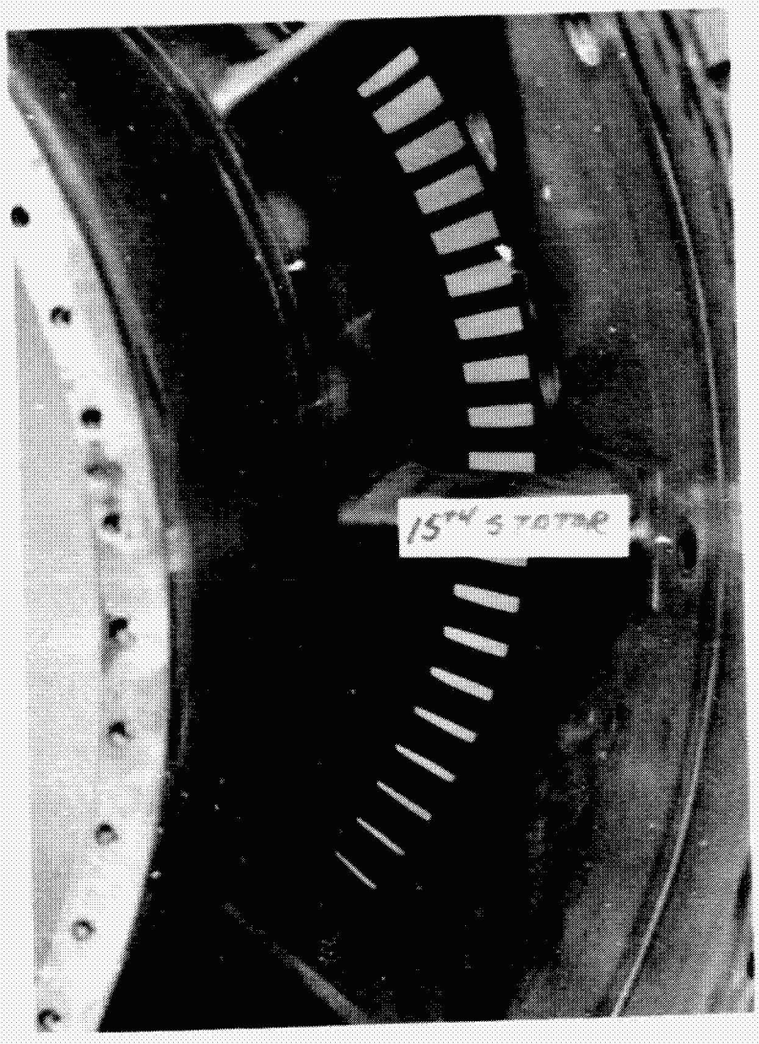
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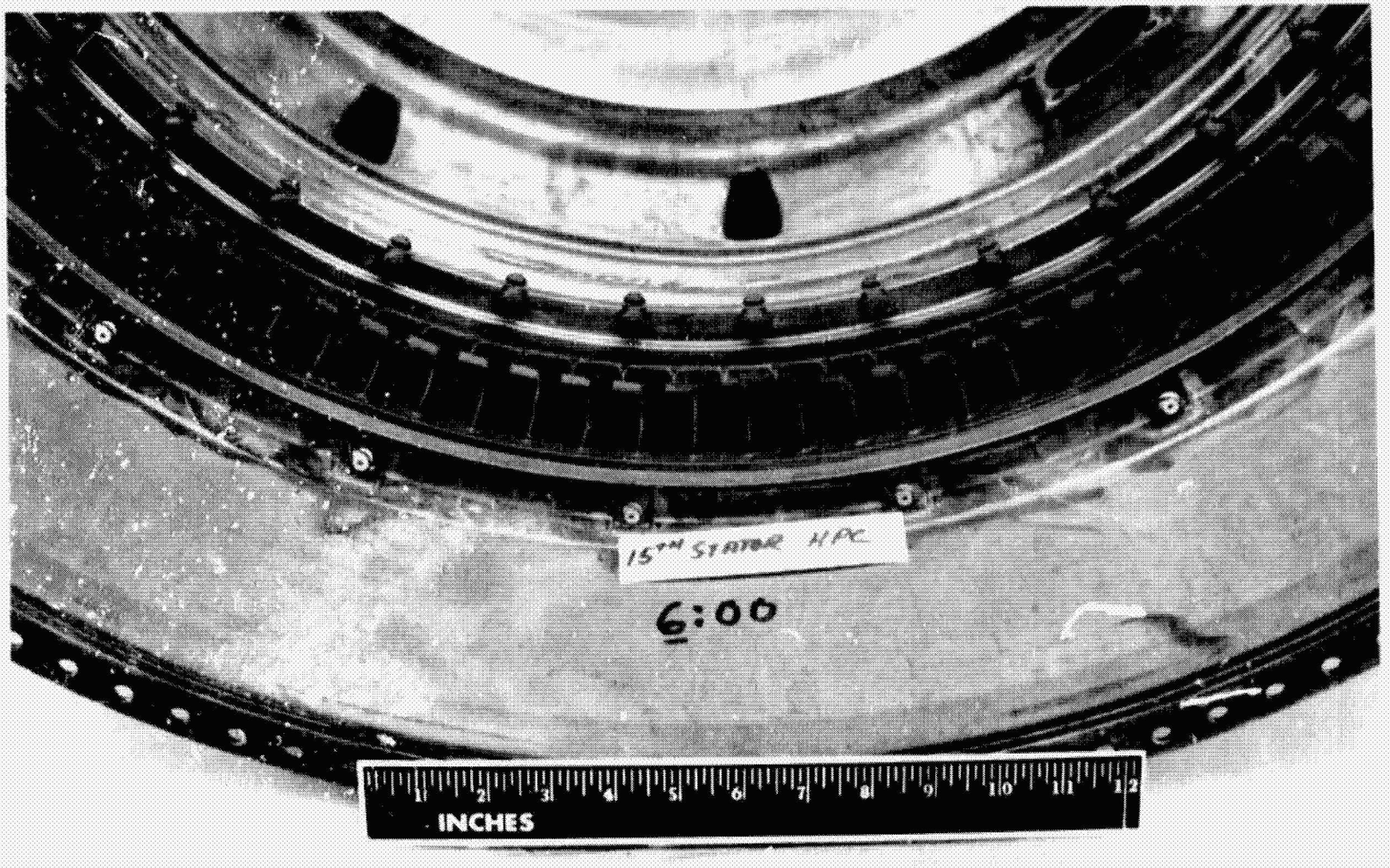
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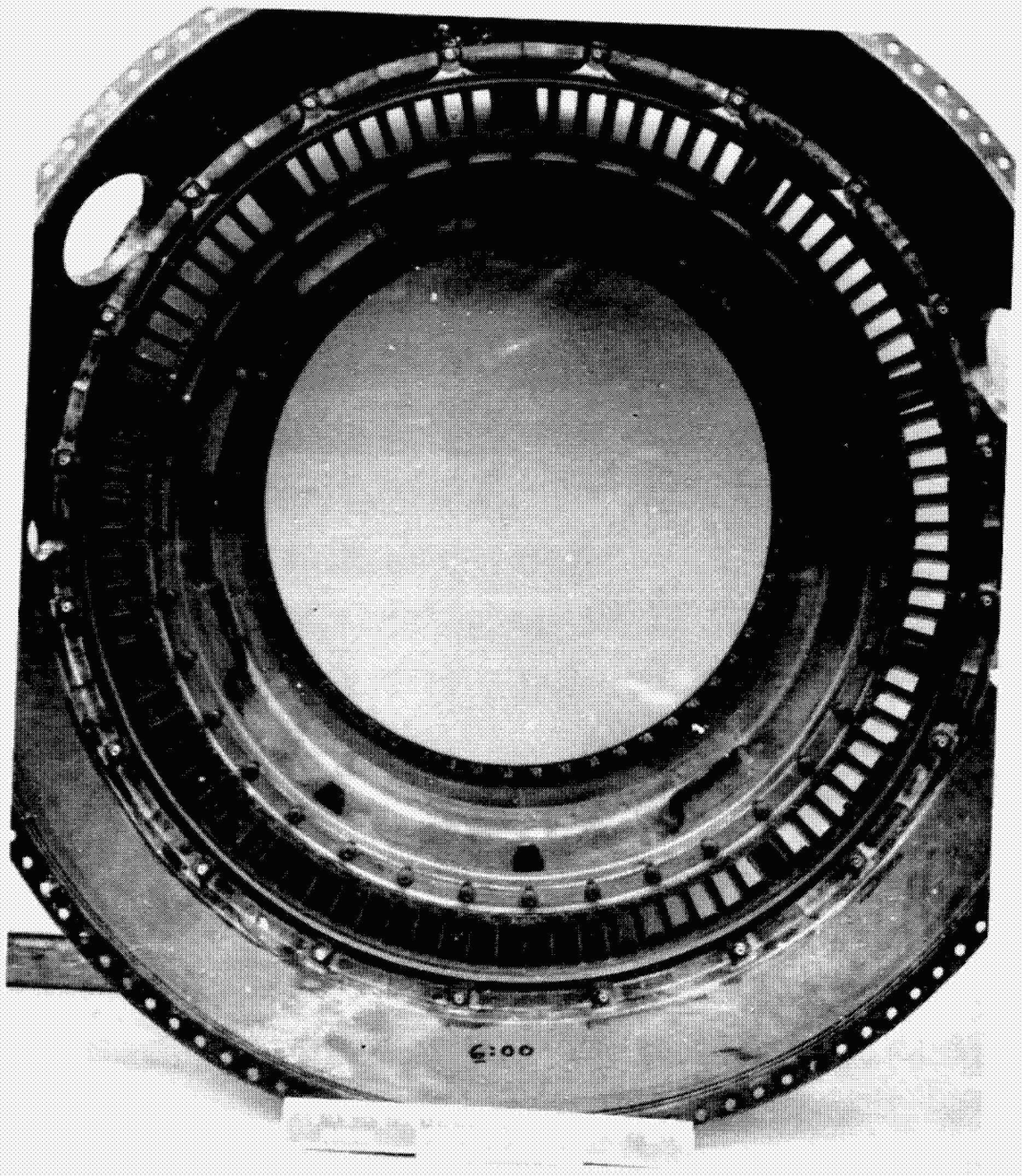
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JT9D Diagnostics Short Term Deteriorated Engine, P-695743, 1081 Hours, 141 Cycles Contract NAS3-20632 Typical LE Condition

77-444-0254-BD

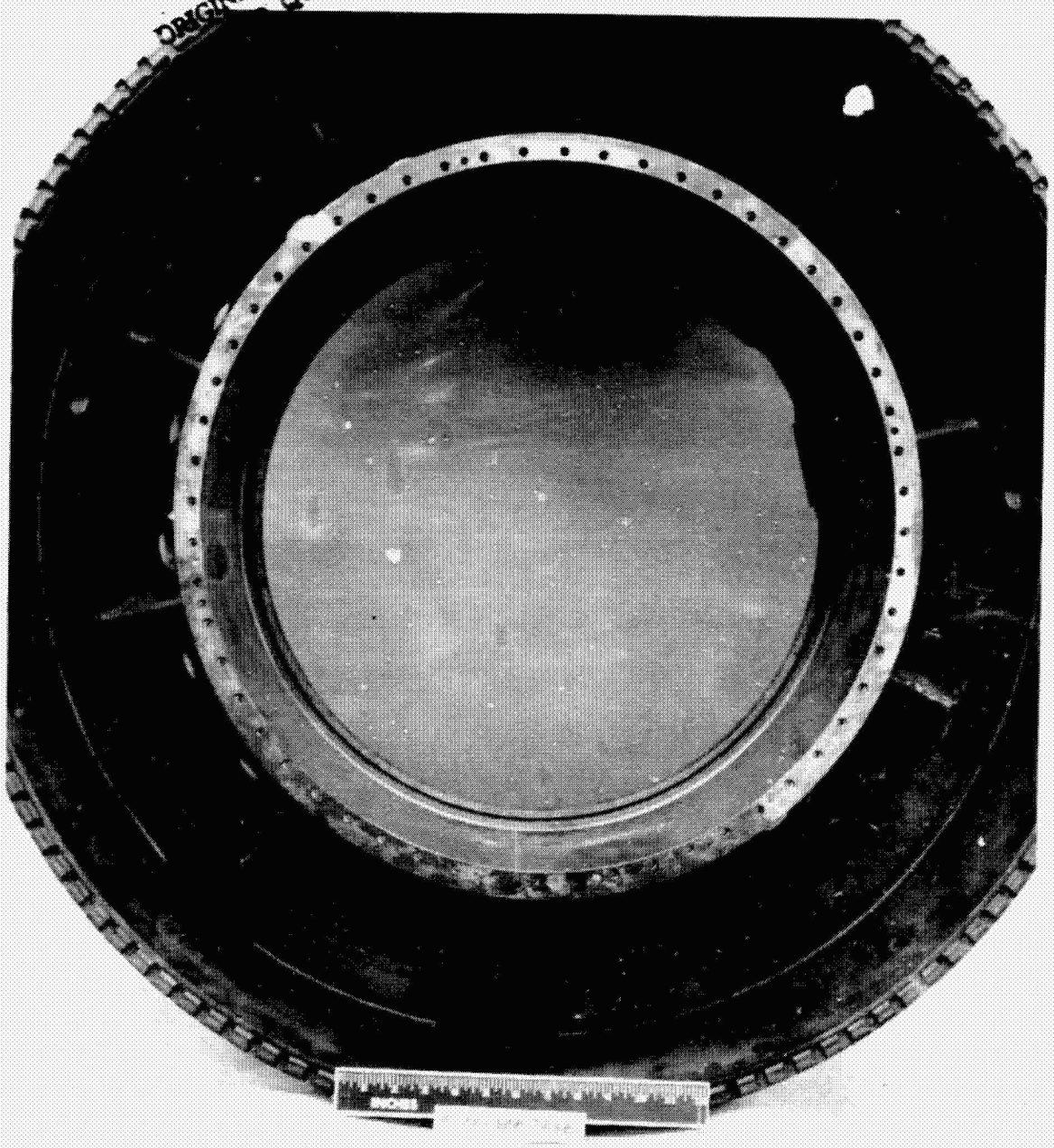
DIFFUSER/COMBUSTOR MODULE



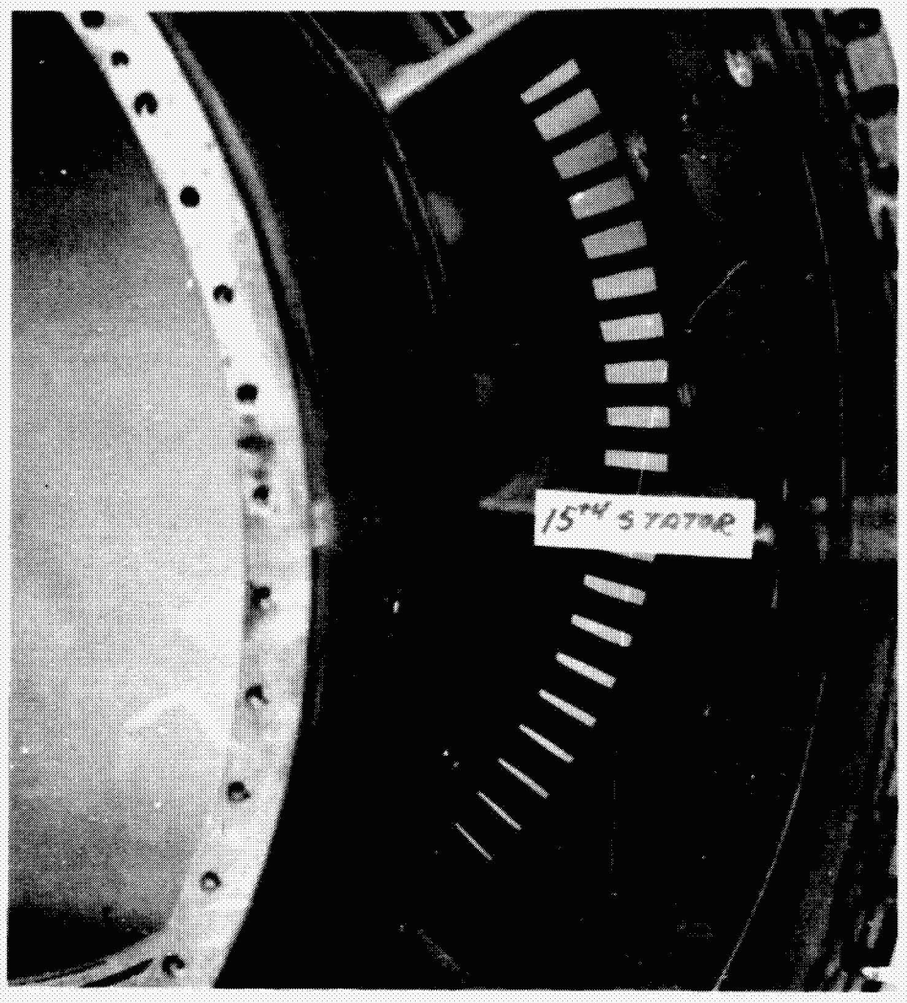
JT9D Diagnostics Short Term Deteriorated Engine, P-695743, 1081 Hours, 141 Cycles Contract NAS3-20632 Front View

77-444-0254-BE

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JT9D Diagnostics Short Term Deteriorated Engine, P-695743, 1081 Hours, 141 Cycles Contract NAS3-20632 Rear View
77-444-0254-BF



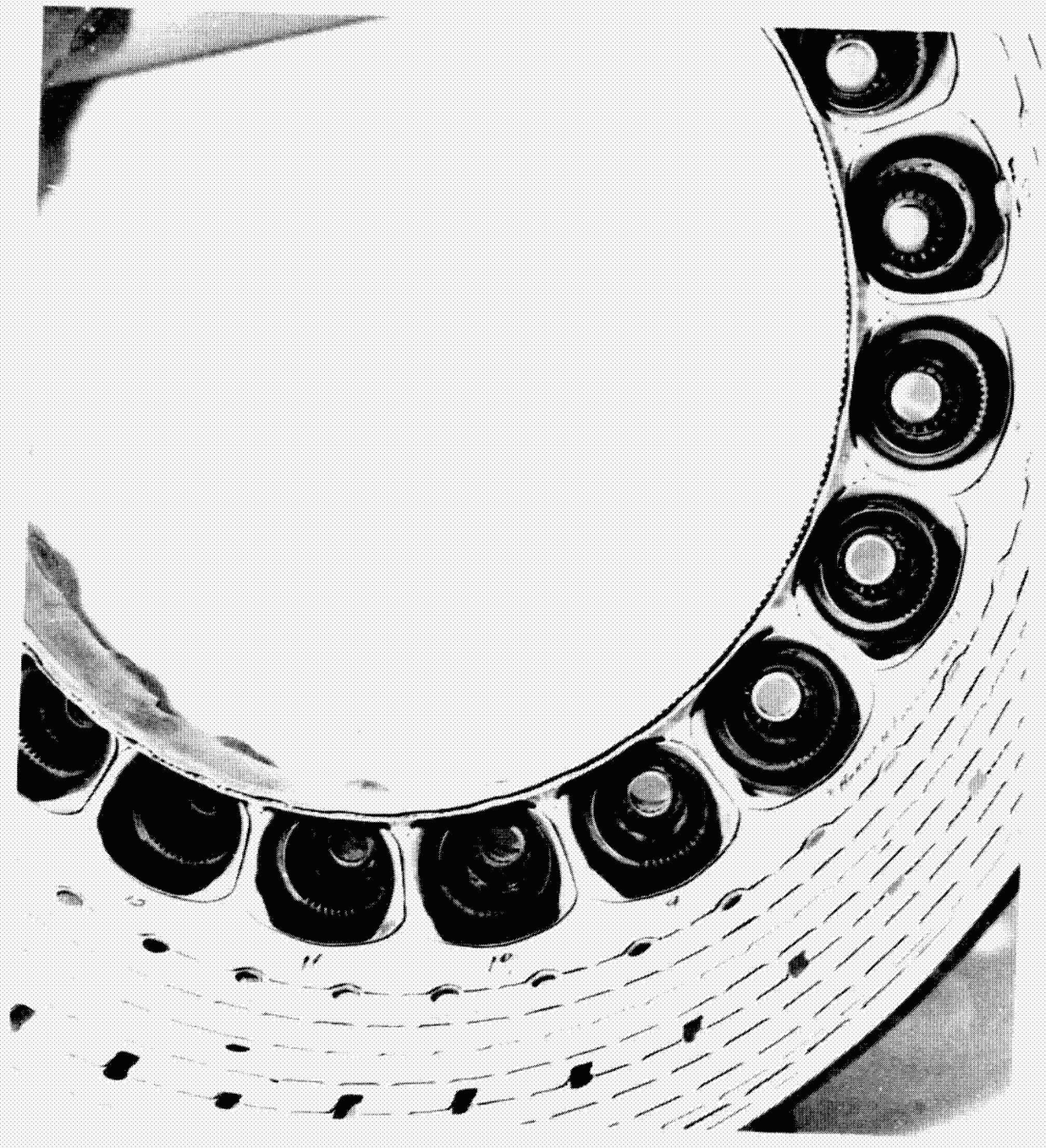
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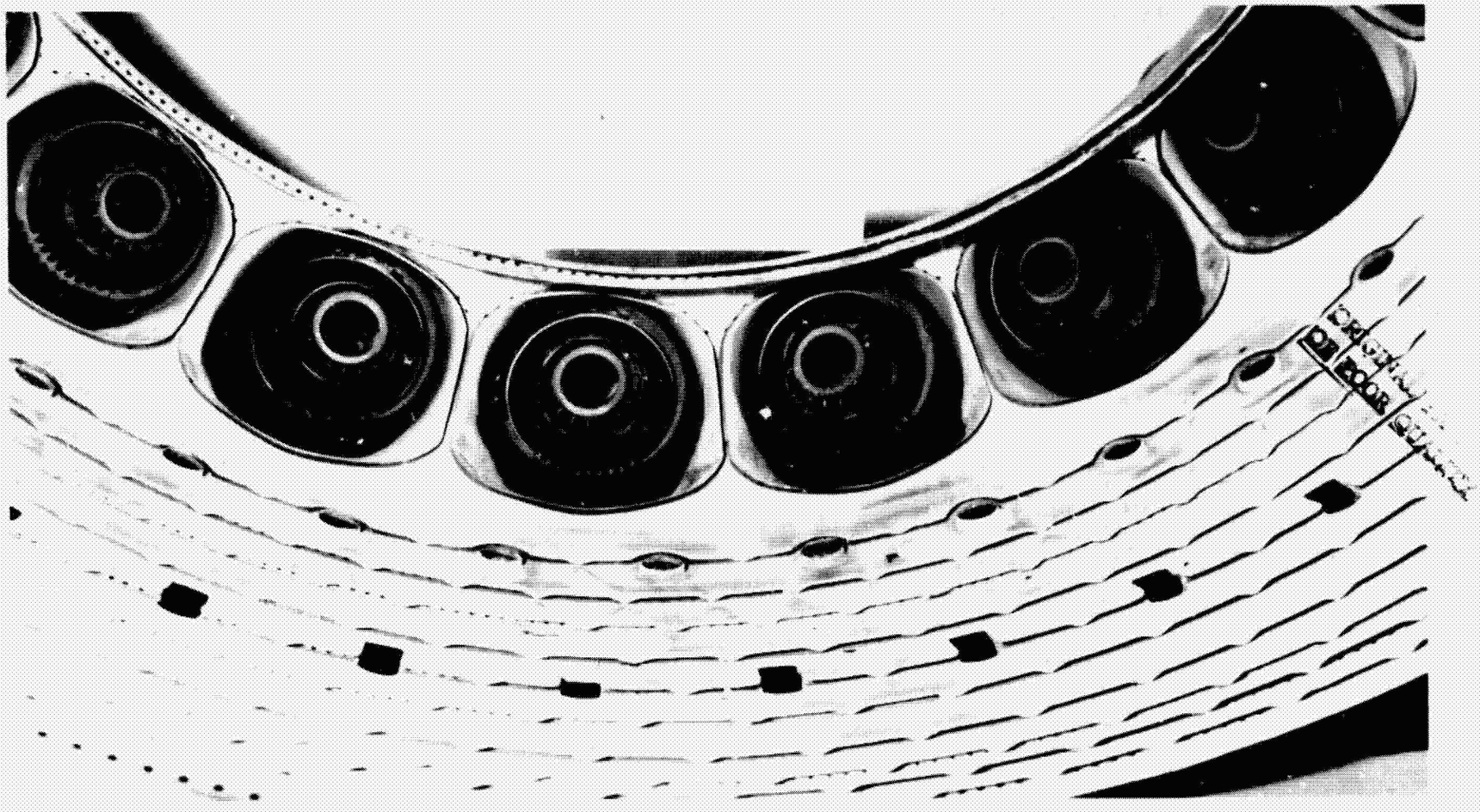
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77-444-0254-AZ



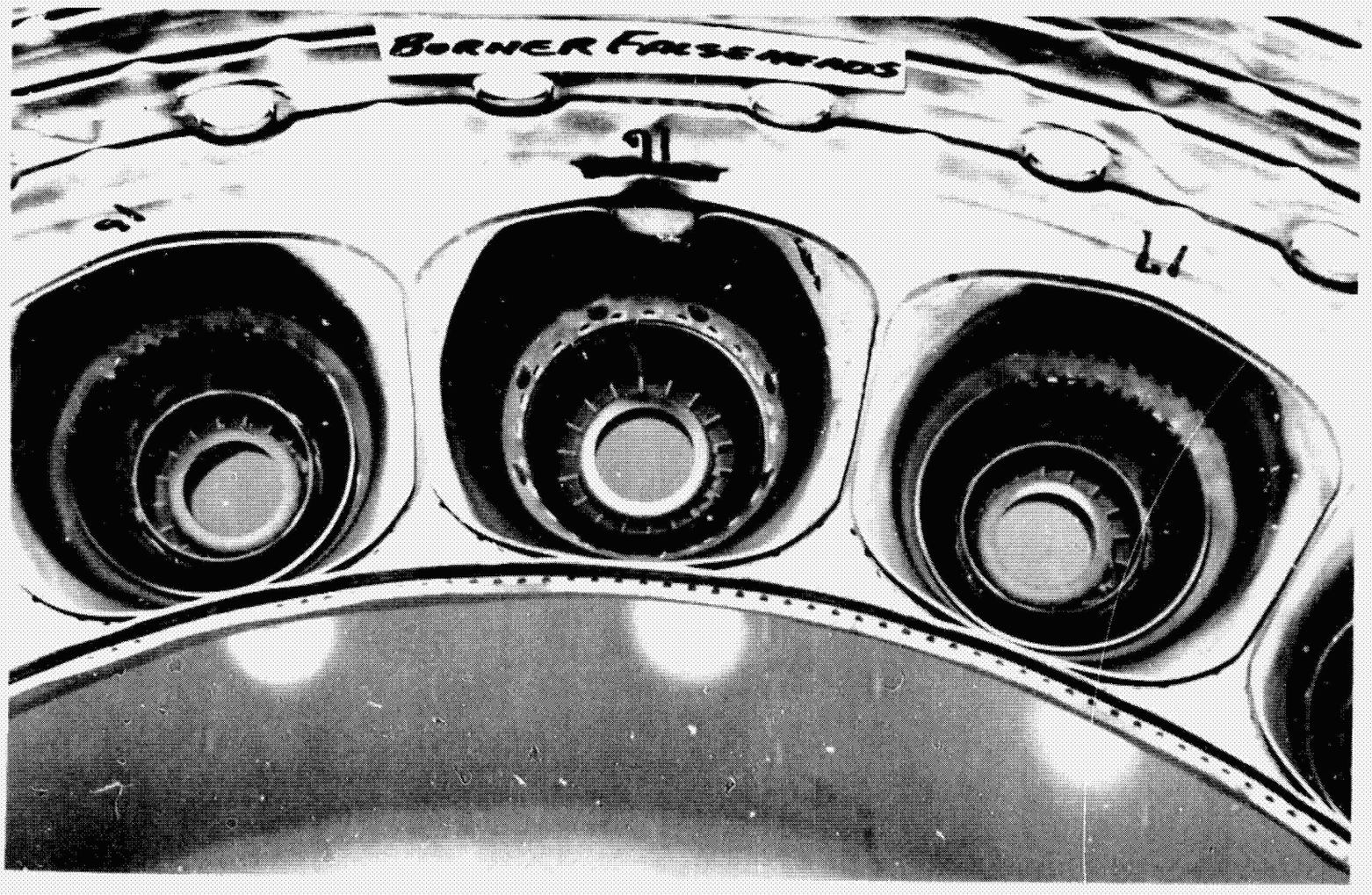
JT9D Diagnostics Short Term Deteriorated Engine, P-695743, 1081 Hours, 141 Cycles Contract NAS3-20632 Typical Burner Condition

77-444-0254-BB



JT9D Diagnostics Short Term Deteriorated Engine, P-695743, 1081 Hours, 141 Cycles Contract NAS3-20632 Burner General Condition

77-444-0254-R



JT9D Diagnostics Short Term Deteriorated Engine, P-695743, 1081 Hours, 141 Cycles Contract NAS3-20632 Worst Burner Condition

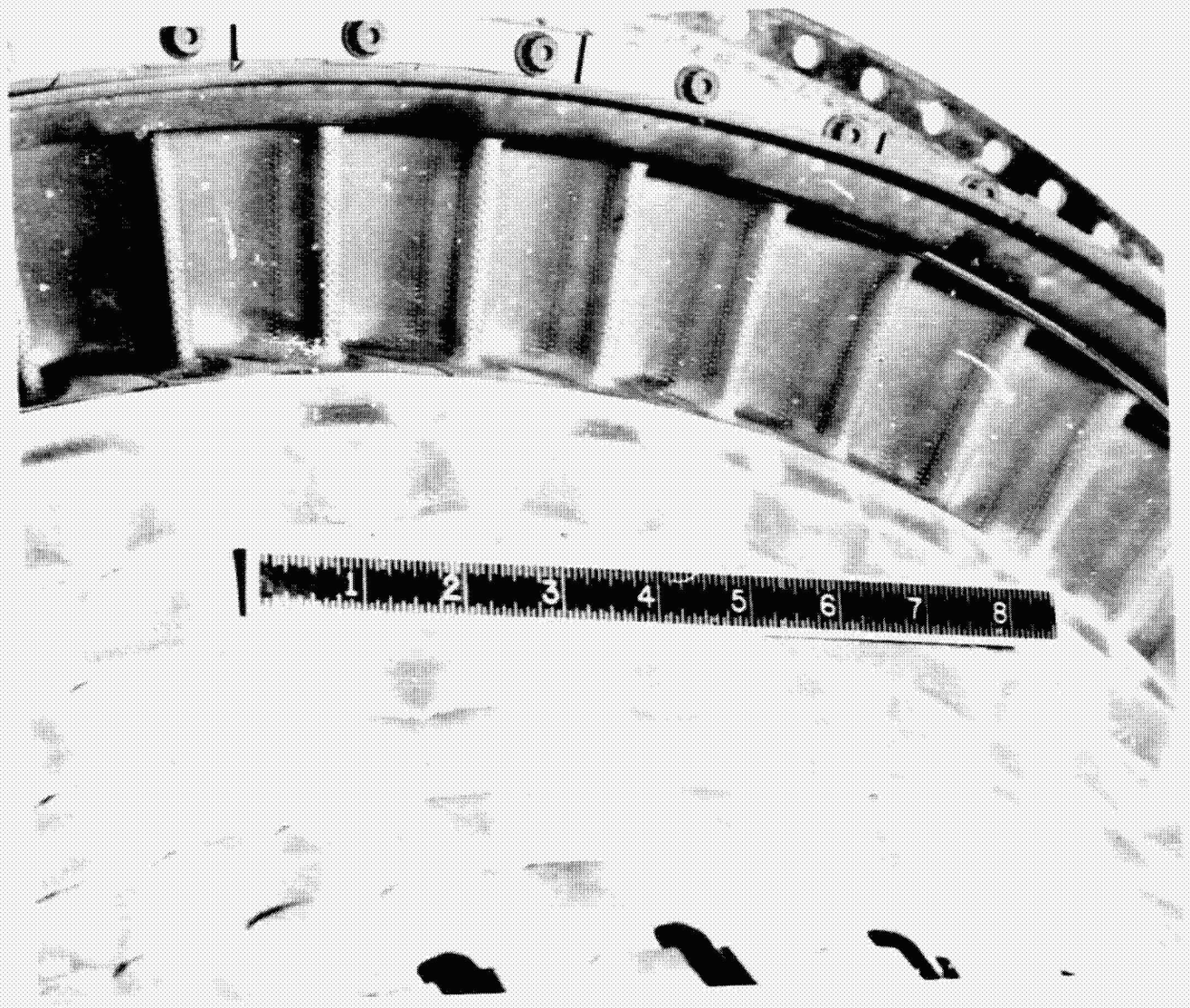
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77-444-0254-N

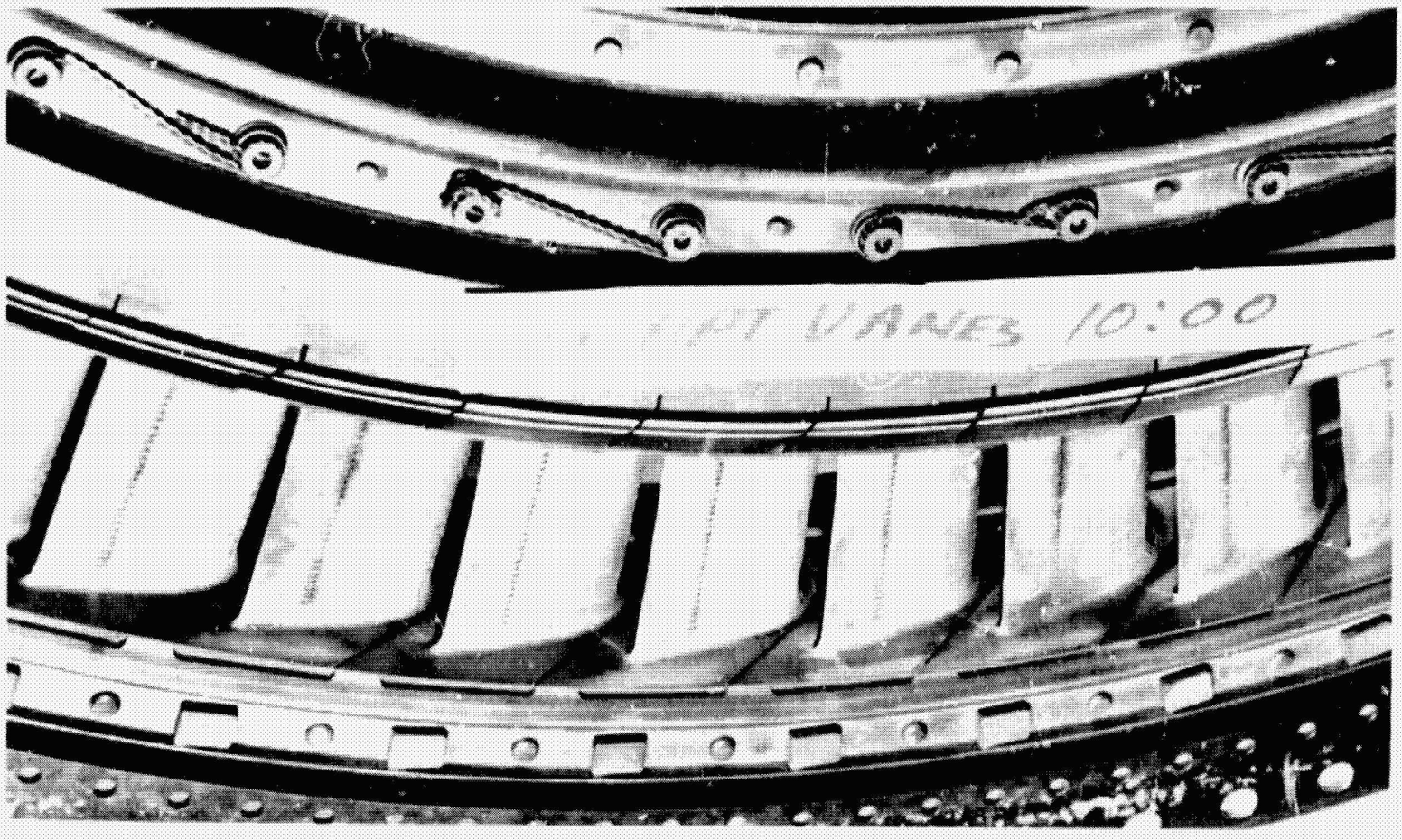
HIGH-PRESSURE TURBINE MODULE

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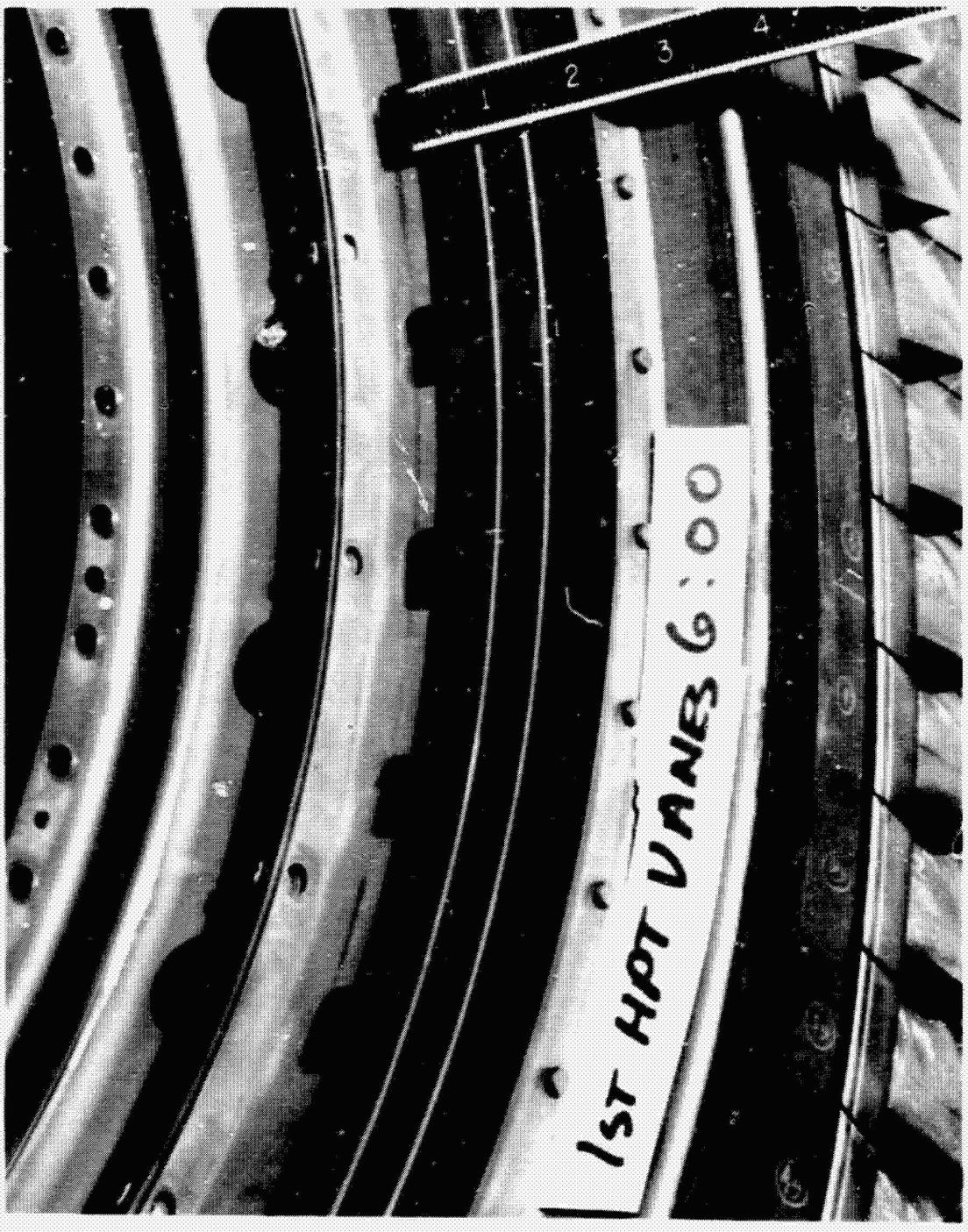
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77-444-0254-O

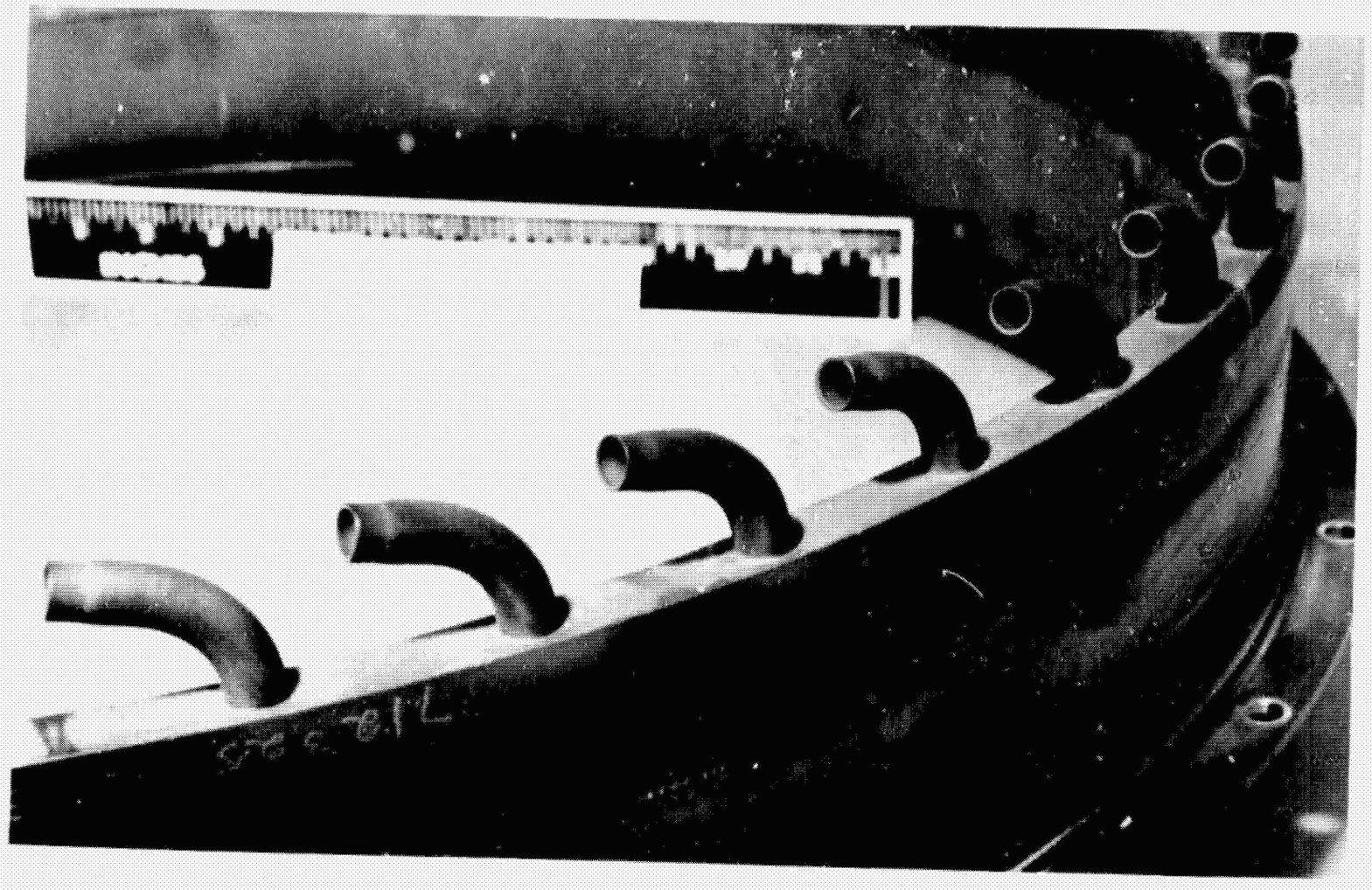


JT9D Diagnostics Short Term Deteriorated Engine, P-695743, 1081 Hours, 141 Cycles Contract NAS3-20632 TE 1st HPT Vane Condition 77-444-02 4-P

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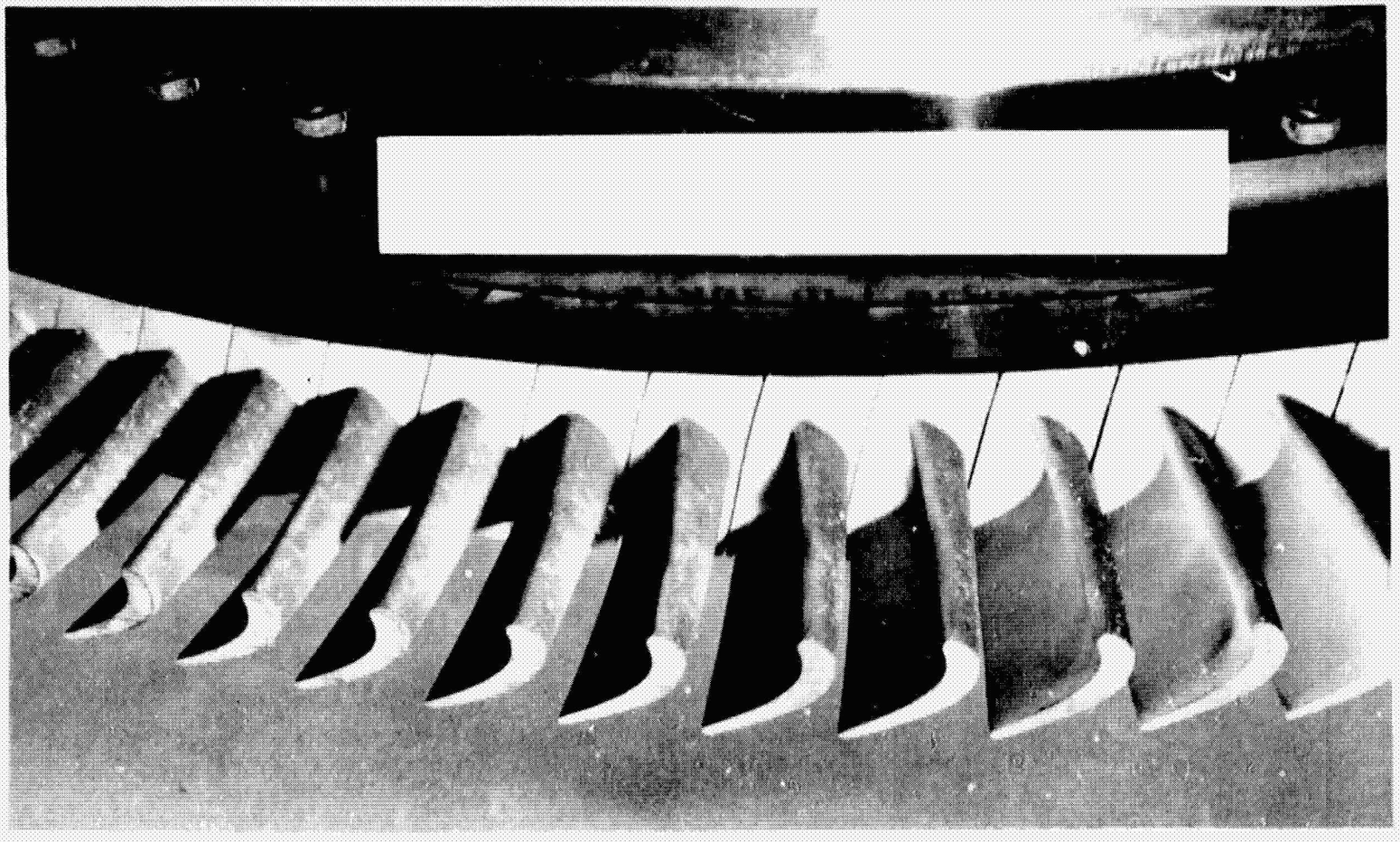


JT9D Diagnostics Short Term Deteriorated Engine. P-695743. 1081 Hours. 141 Cycles Contract NAS3-20632 Vanes & Inner Seal General Conditions 77-444-0254-M

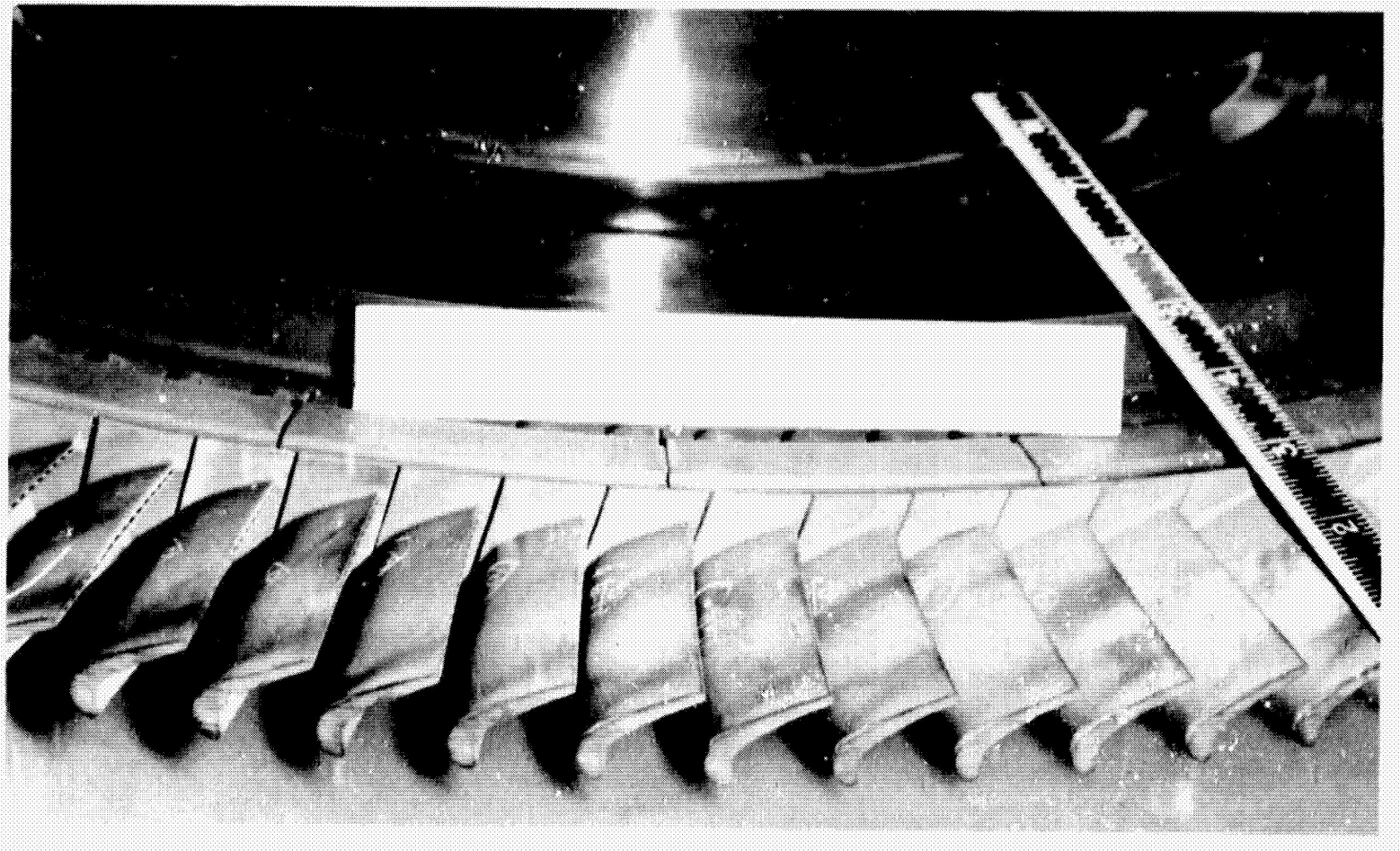


JT9D Diagnostics Short Term Deteriorated Engine, P-695743, 1081 Hours, 141 Cycles Contract NAS3-20632 Typical TOBI Nozzle Condition

77-444-0254-AY



JT9D Diagnostics Short Term Deteriorated Engine, P-695743, 1081 Hours, 141 Cycles Contract NAS3-20632 LE & Tip Condition 1st HPT Blades 77-444-0254-Q



JT9D Diagnostics Short Term Deteriorated Engine, P-695743, 1081 Hours, 141 Cycles Contract NAS3-20632 Blade Tip Wear And Rub Indications 77-444-0254-S



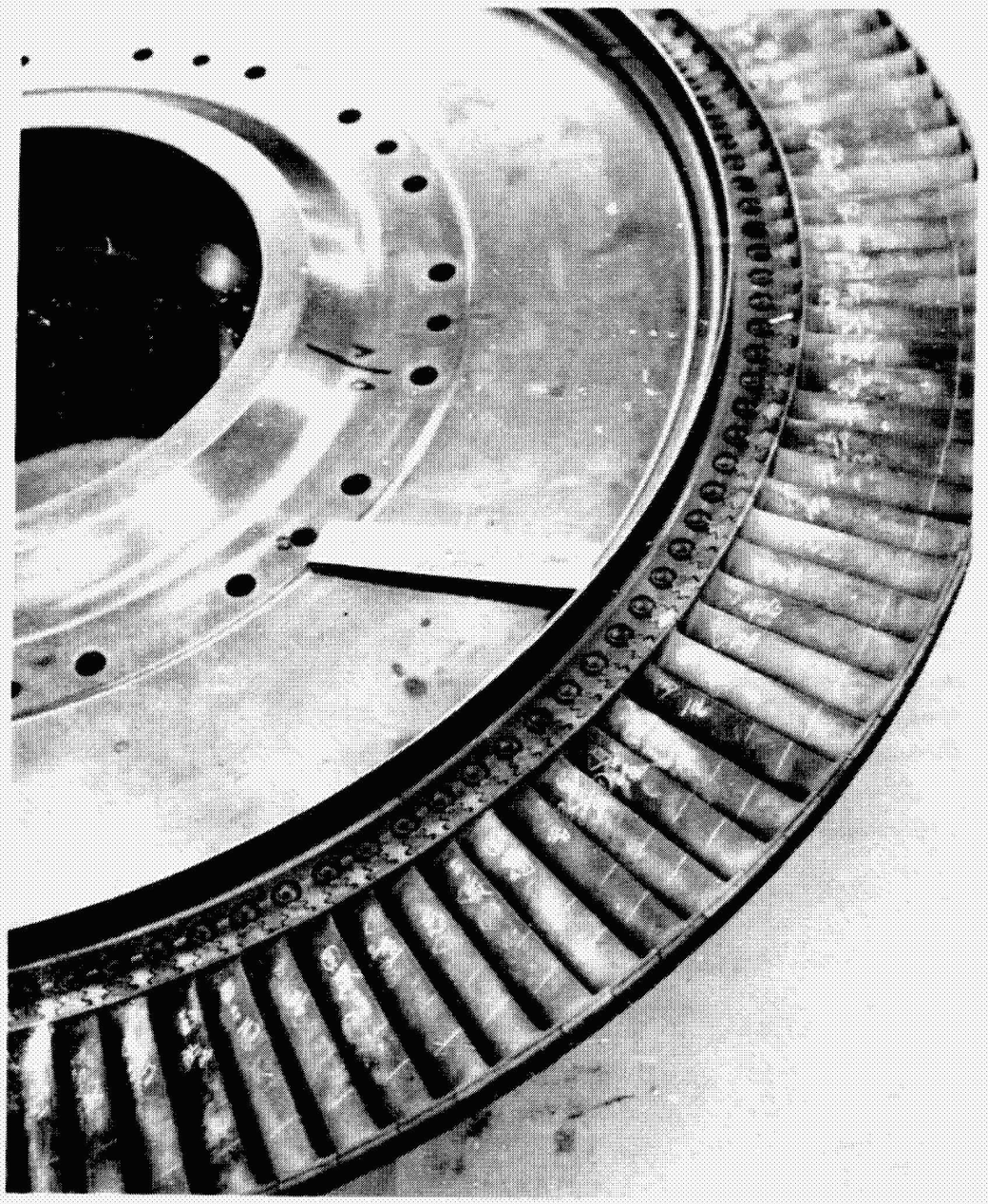
JT9D Diagnostics Short Term Deteriorated Engine, P-695743, 1081 Hours, 141 Cycles Contract NAS3-20632 Maximum OAS Rub Pattern

77-444-0254-T



JT9D Diagnostics Short Term Deteriorated Engine, P-695743, 1081 Hours, 141 Cycles Contract NAS3-20632 LE Condition

77-444-0254-AW



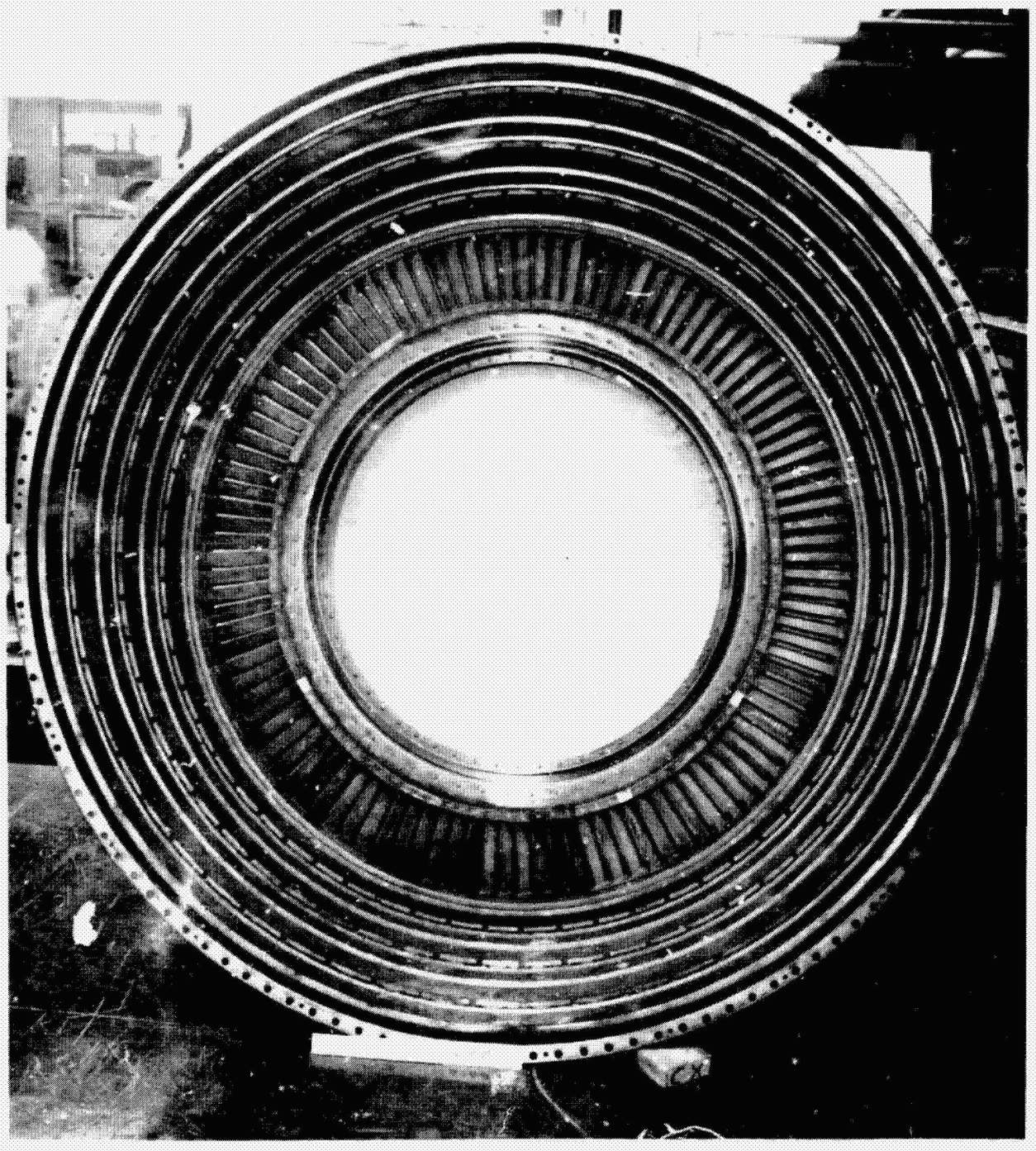
JT9D Diagnostics Short Term Deteriorated Engine. P-695743. 1081 Hours. 141 Cycles Contract NAS3-20632 TE Condition

77-444-0254-BL

JT9D Diagnostics Short Term Deteriorated Engine, P-695743, 1081 Hours, 141 Cycles Contract NAS3-20632 2nd HPT OAS Rub & Wear Pattern
77-444-0254-U

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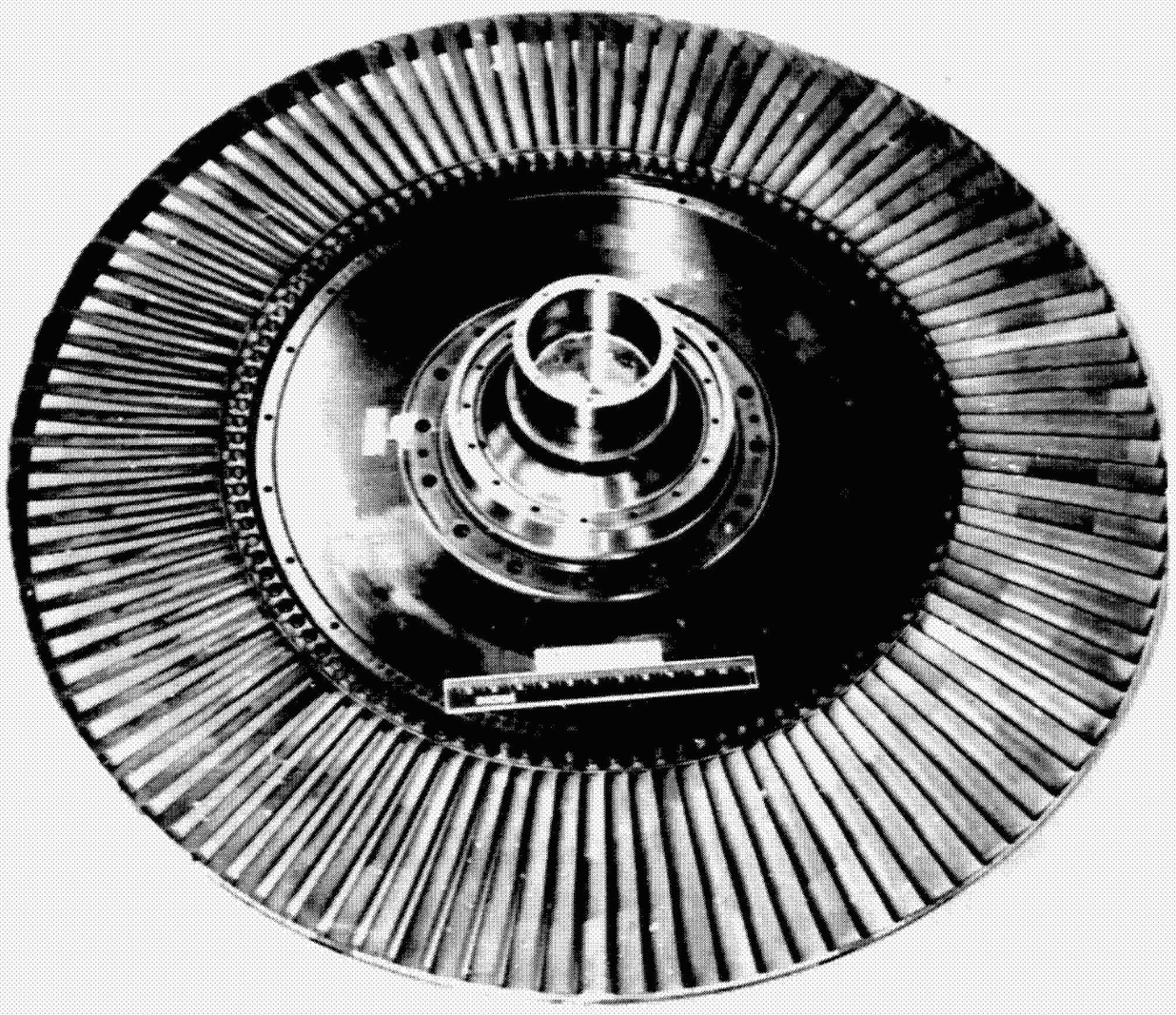
LOW-PRESSURE TURBINE MODULE



JT9D Diagnostics Short Term Deteriorated Engine, P-695743, 1089 Hours, 141 Cycles Contract NAS3-20632 LPT Case & 3rd Vanes General Condition 77-444-0254-AA

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77-444-0254-BC



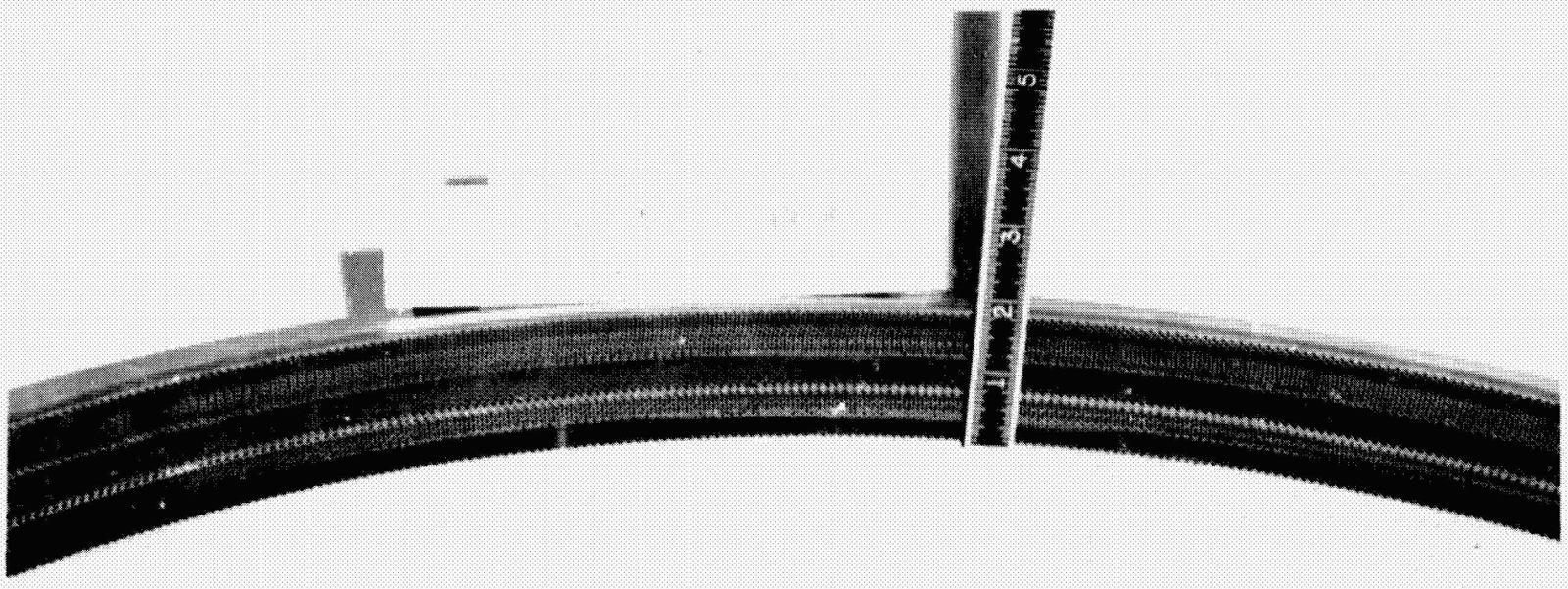
JT9D Diagnostics Short Term Deteriorated Engine, P-695743, 1081 Hours, 141 Cycles Contract NAS3-20632 Typical Rotor TE 77-444-0254-AX

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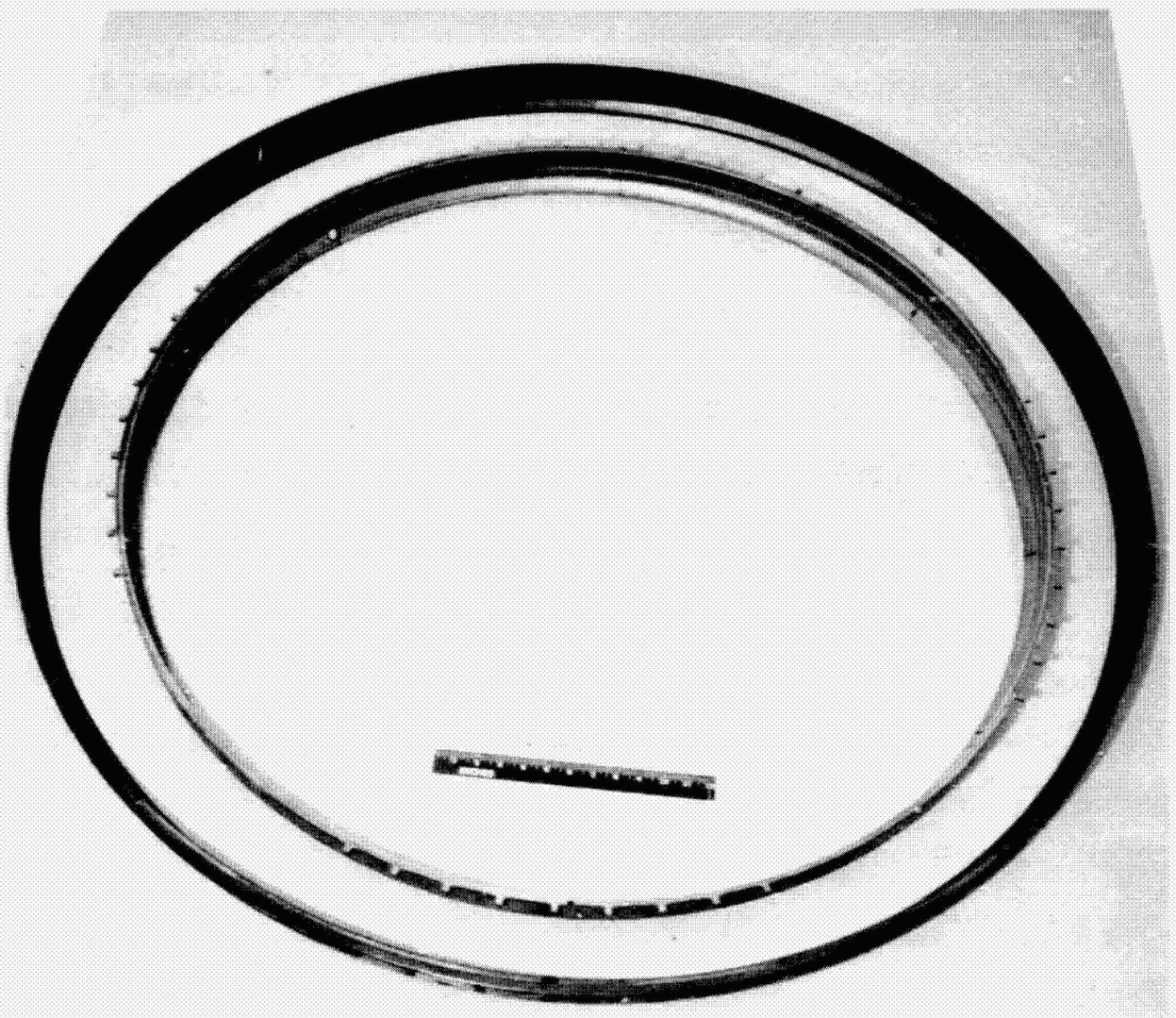
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JT9D Diagnostics Short Term Deteriorated Engine, P-695743, 1081 Hours, 141 Cycles Contract NAS3-20632 Typical Inner KE Seal Rub Indications
77-444-0254-V

JT9D Diagnostics Short Term Deteriorated Engine, P-695743, 1081 Hours, 141 Cycles Contract NAS3-20632 LPT OAS Rub & Wear Pattern
77-444-0254-X



JT9D Diagnostics Short Term Deteriorated Engine, P-695743, 1081 Hours, 141 Cycles Contract NAS3-20632 LPT Inner KE Rub & Wear Pattern 77-444-0254-W



JT9D Diagnostics Short Term Deteriorated Engine, P-695743, 1081 Hours, 141 Cycles Contract NAS3-20632 Typical OAS Condition 77-444-0254-AV

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APPENDIX H

POST-TEARDOWN CALIBRATION LOG SHEET SUMMARY

SUMMARY

LOG OF ENGINE TEST.

ENGINE # P695743 JT9D-7ASP CELL # S DATE 10/28/77 TIME 1609

ENGINEERING REQUIREMENTS

FSLHV 18550.

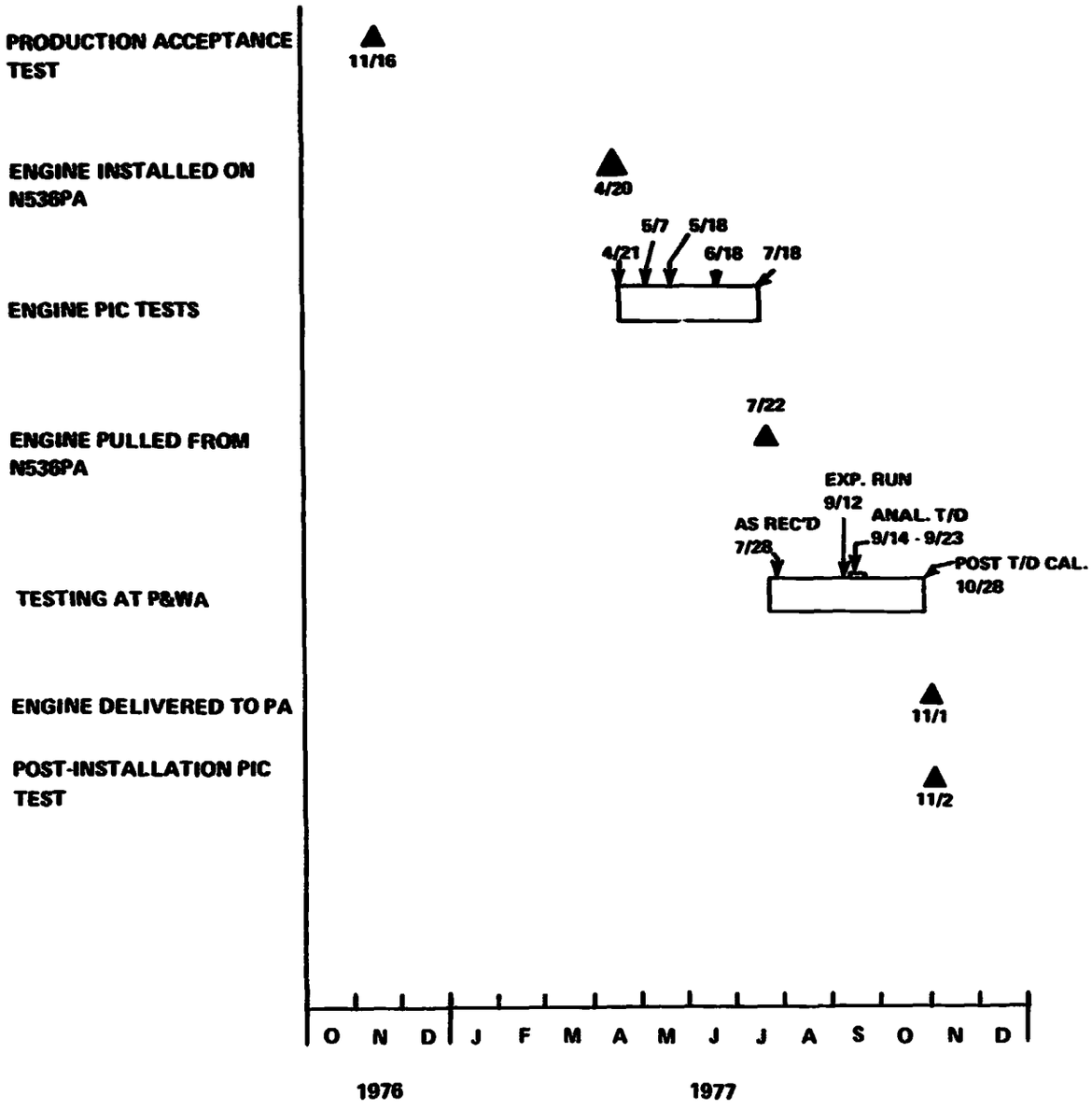
FN/ST2	TSFC % DEVIATION
46150.	.6
40080.	.2
37275.	-.0

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APPENDIX I

PROGRAM CHRONOLOGY

P-695743 TASK IIIA ENGINE CHRONOLOGY



APPENDIX J

NOMENCLATURE

APPENDIX J

NOMENCLATURE

CDLA	- Condition lever angle (degrees)
Eff	- Efficiency (percent)
EGT	- Exhaust gas temperature (°F) (°K)
EPR	- Engine pressure ratio
F	- Engine thrust (pounds)
HPC	- High-pressure compressor
HPT	- High-pressure turbine
LPC	- Low-pressure compressor
LPT	- Low-pressure turbine
N	- Rotor speed (rpm)
P	- Pressure (lb/in^2) (psia)
PLA	- Power lever angle (degrees)
T	- Temperature (°F) (°K)
W	- Mass flow (lbm/sec)
β	- Vane angle (degrees)
Δ	- Change
δ	- Pressure correction (in. Hg/29.92)
η	- Efficiency (percent)
$\sqrt{\theta}$	- Temperature correction (°R/519)

Subscripts:

1	- Undisturbed inlet (pressures and temperatures)
	- Low-pressure rotor (rotor speeds)
2	- Fan inlet (pressures and temperatures)
	- High-pressure rotor (rotor speeds)
2.4	- Fan blade discharge
2.6	- Fan exit guide vane discharge
3	- LPC discharge
4	- HPC discharge
5	- HPT inlet
6	- HPT discharge
7	- LPT discharge
A, a	- Ambient
AM, am	- Ambient
b	- Burner

APPENDIX J

NOMENCLATURE (Cont'd)

F, f	- Fuel
N, n	- Net
s	- Static
T, t	- Stagnation (total)